ISSN 1173-5996

Sprinkler Trade Off Clauses in the Approved Documents

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Fire Engineering Research Report 97/1
May 1997

This report is based on a project report presented as part of the M.E.(Fire) degree at the University of Canterbury

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Abstract

Sprinkler trade offs are clauses in the approved documents that allow various reductions in passive protection, maximum fire cell areas or maximum path lengths where an approved sprinkler system is present.

Sprinkler trade offs have been present in New Zealand since they were introduced into NZS 1900 Chapter 5 in its 12th amendment in 1978. They have been progressively added and to NZS 1900 Chapter 5 and more recently to the Approved Documents of the New Zealand Building Code, up to the final ammendment in December 1995.

By conducting an analysis of the approved documents and overseas building codes, a risk analysis and a cost benefit analysis this report concludes that sprinkler trade off clauses are a valuable tool in ensuring fire safety in this country. If the clauses are utilised the protection will be economical over 30 years and not endanger the occupants of the buildings or their contents.

The level of trade offs is presently set at a level that may be considered a bare minimum to ensure safety in the event of a sprinkler failure.

In specific situations where property protection may be lowered by the removal of some passive systems, it may be prudent for the owner to not use all the permitted trade offs, especially if the building contents are valuable or considered vital to business.

Acknowledgements

The research described in this report was made possible with the financial support of Winstone Wallboards Ltd and The New Zealand Fire Service Commission. I would especially like to thank Hans Gerlich of Winstone Wallboards for his advice and encouragement.

Completion of this project would not have been possible without the invaluable assistance of the following people who I thank for taking time out of their busy schedules to answer my questions.

- Cliff Barnett
- Norman Bridge
- Peter Byrne
- Charles Clifton
- John Fraser
- Sandy Lawson
- Pancha Narayanan
- Martyn Spencer
- Colleen Wade

I would also like to thank my supervisor Dr. Charles Fleischmann for his guidance.

Finally I would like to thank my fellow students James Boyes, Thomas Grace, Kevin Irwin, Derek Robertson, and Anthony Walker for their suggestions and enthusiasm.

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Nomenclature

A_O = Recurring annual sum to be paid over a period of n years ($)
A_f = Floorspace in a firecell (m^2)
A_h = Horizontal openings in the firecell (m^2)
A_v = Vertical openings in the firecell (m^2)
i = Discount rate
L = Fire loss (human + property) expectation (dollars per year per square metre floor area)
l_P = Average loss (human + property) resulting from fires that do not reach flashover (dollars per incident)
l_{FN} = Average loss (human + property) resulting from post flashover fires that do not spread (dollars per incident)
l_{FSD} = Average loss (human + property) resulting from post flashover fires that spread by destruction (dollars per incident)
l_{FSC} = Average loss (human + property) resulting from post flashover fires that spread by convection (dollars per incident)
n = Expected lifetime of the system (years)
N = Expected number of fire incidents (per year per square metre of floor area)
P_P = Probability that, given ignition, the fire will not reach flashover
P_{FN} = Probability that, given flashover, the fire will not spread to other compartments
P_{FS} = Probability that, given flashover, the fire will spread
P_{FSD}= Probability that, given flashover, the fire will spread to other compartments by destruction
P_{FSC} = Probability that, given flashover, the fire will spread to other compartments by convection (by the advance of flames and hot gases)
UPW = Uniform present worth ($)

1. Introduction

Sprinkler trade offs are clauses in the approved documents that allow various reductions in passive protection, maximum fire cell areas or maximum path lengths where an approved sprinkler system is present.

Sprinkler trade offs have been present in New Zealand since they were introduced into NZS 1900 in its 12^{th} amendment in 1978. They have been progressively added and to NZS 1900 Chapter 5 and more recently to the Approved Documents of the New Zealand Building Code, up to the final ammendment in December 1995.

Although these clauses are well established and frequently utilised very little has been written on how these clauses are justified and, in the event of a fire, how the structure is expected to react. To meet the requirements of the New Zealand Building Code the safety of the occupants, the safety of Fire Service staff and the safety of other property must be guaranteed. By conducting various forms of analysis this report hopes to comment on whether these basic requirements have been fulfilled and look further to determine how these clauses effect property protection.

1.1. Method

There are many effects the trade off clauses have on the construction and renovation of buildings in this country, by looking at all of these effects this report hopes to develop a well balanced analysis of the clauses.

The initial study consists of a literature review in which previous attempts to analyse trade off theory are examined. A critical analysis of each will be completed and conclusions drawn.

The only area relevant to the New Zealand Building Code is that of life safety and the protection of other peoples property. Although various methods have been used to analyse trade off clauses in the past the most obvious method of determining the life safety of the trade off clauses is by conducting a risk analysis. The risk analysis used will consider the possibility of failure of the sprinkler system and spread of fire through the structure.

Property protection is of no interest to the Building Code, however it is of great interest to property owners and insurers. Even if by utilising the trade off clauses life safety is assured they may still place property at greater risk from fire. To investigate this effect a cost benefit analysis will be conducted.

By considering all of the above aspects conclusions will be drawn on how trade off clauses effect property and life safety and how they should be used in the future.

2. Types of Protection

To understand balancing and trading between differing levels of two distinct types of fire protection it is first essential to define the types of protection into two categories and to understand how each of these systems work. It would also be of interest to know how and when each of these systems fail to complete their desired function.

2.1. Passive Protection

Passive protection consists of any sort of protection that does not react to the fire. This typically consists of one of two methods each for a specific purpose.

To prevent the spread of smoke and flame throughout a building partitions separating a building into various firecells are commonly used. Each firecell is separated from the others by a solid mass rated to resist a fire for a length of time (or F rating). This limits the fire to one compartment for a length of time designed to allow the evacuation of building occupants in danger and limit the size of the fire to allow effective fire fighting operations.

To ensure the structure remains stable major structural elements are rated to withstand the effects of fire for a length of time (or S rating). This rating ensures the structure will not collapse and harm property adjacent to the fire.

2.1.1. Advantages

The main advantage of passive systems over active systems is that they are insulated from any effects from outside the building. By not relying on any other systems this form of protection is immune from problems with services such as electricity or water supplies. Therefore, in the event of an earthquake or other natural disaster they could be expected to be more reliable.

2.1.2. Disadvantages

The disadvantage of passive protection is that, by definition, it does not react to the fire. As passive protection is only rated for a finite length of time without further intervention from the fire service or any other outside influence the entire contents and lining of a building will be lost, although the structure is expected to remain stable.

Further failings of passive systems lie in the fact that unlike active protection systems they are not subject to stringent testing and maintenance procedures, this results in the fact that over time the passive system is likely to become compromised. Changes to the structure, new cables or plumbing are all likely to be placed through fire rated walls and there is every chance they will not be sealed properly. Even the smallest of gaps around a wall penetration can lead to the failure of a passively rated wall as flame spreads to the adjacent compartment and attacks the partition from both sides.

2.1.3. Potential Failures

Passive systems are expected to withstand the effects of fire for at least their rating. Usually this is true but it does not take in to account the spread of smoke and flame around the barrier through open doors, windows or holes for services as shown in Figure 1

As the fire spreads around the separation burning begins to occur on both sides of the partition and it will break down much faster than expected and allow the further spread of fire to occur at a much greater rate.

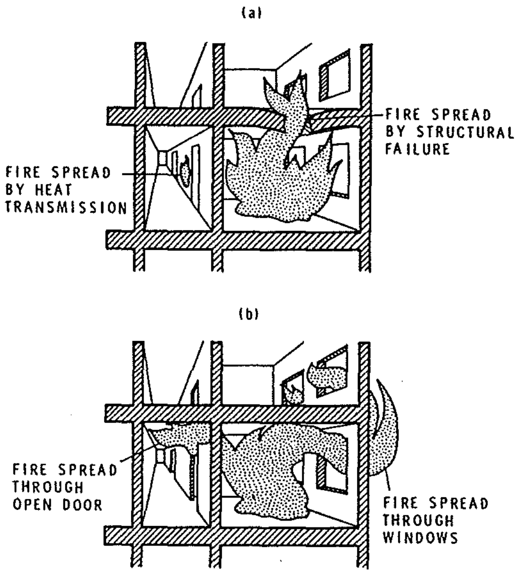

Figure 1; Assumed (a) and actual (b) failures of passive systems

2.2. Active Protection

Active systems by definition react to the fire and move to surpress it by the application of a gas or liquid. Sprinklers are by far the most common form of active protection. Sprinklers consist of a network of sprinkler heads on the ceiling or roof of a firecell each connected to the others by piping charged with pressurised water. If any of these heads reach a temperature above a predetermined value (usually 50-70°C) the head will operate and apply water to the area below, thereby at least limiting the growth of the fire. In most cases a single sprinkler head will surpress and eventually extinguish the fire.

2.2.1. Advantages

The active system, when it is designed and maintained correctly, it is expected to extinguish the fire in 67%[i1] of cases or restrict the fire to a small size until it is extinguished by other means (usually an occupant) in over 99% of cases. This effectiveness and reliability have combined to give sprinklers an excellent record in this country. Sprinklers are now acknowledged to protect both life and property except in extreme cases.

The effect of water being applied to the base of the fire so early in its development is very beneficial. Sprinklers will cause a mixture of cooling and oxygen depletion to slow combustion and pre-wetting of adjacent fuels to reduce the spread of the fire. In a sprinkler controlled fire the compartment temperature is not expected to rise above 300°c.

2.2.2. Disadvantages

The major disadvantage of an active system is that it relies on water provided (usually) from outside the system. Vandals and arsonists can tamper with this supply to render the system inoperable or a natural event such as an earthquake can destroy the piping required for this supply. In these cases a sprinkler system is rendered inoperable and fire protection will rely totally on passive systems.

The type of fire can also greatly influence the sprinkler systems performance. In the case of an explosion followed by fire the sprinkler system may be rendered inoperable due to pipework being destroyed. At the other end of the scale smouldering fires may not produce enough heat at the sprinkler heads to operate the system. Fires of this type will still produce large amounts of smoke that could cause extensive property damage, or in extreme cases threaten life safety.

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[1] The numbers in italics refer to references at the end of this document

As water is applied to the fire the smoke generated by the fire has its composition substantially altered. Large amounts of superheated steam are added to the products of combustion to produce a gas which carries much more heat. The steam in the smoke, if inhaled, will heat the throat and lungs of the victim to a much greater extent than smoke alone would creating a greater threat to life safety[ii]. Balanced against this effect is the fact that the amounts of smoke and heat produced by the fire are limited by application of water.

The application of water from a sprinkler system will also cool the smoke produced by a fire making it less buoyant, this will greatly influence the way in which the smoke will travel through the structure. In this case systems designed to deal with the smoke such as extraction and venting systems may not function as designed leading to a greater hazard.

2.2.3. Potential Failures

Active systems are far more complicated than passive systems and therefore are likely to suffer from a lower reliability. This is offset in this country against the strong inspection and maintenance procedures that are required by NZS 4541.

Failures in sprinkler systems usually occur at the point where the water supply enters the building. Valves may be tampered with or set in the wrong position rendering the system inoperable or the water supply may have been disrupted further from the building due to a broken water main.

Another potential failure occurs if the contents of a sprinklered space are changed and the fire hazard increased without any alterations to the sprinkler system. This means there is potential for a fire to grow faster than the sprinkler system is designed to cope with and the sprinkler system may be overpowered as many heads operate and the pressure (and therefore the water available to each head) drops.

A failure that is becoming increasingly common as storage methods change is the shielding of the fire by storage racks. In rack sprinkler systems have been designed to deal with this situation but building owners are hesitant to install a system that will limit their flexibility in the future by fixing the racks in position.

Also seen in storage situations is plastic wrapping of pallets or packages of goods, in these cases the sprinkler system is unable to pre-wet the fuel which may lead to a much greater spread of fire.

3. Sprinkler Trade Off Clauses

Sprinkler trade off clauses appear in many forms in many building codes around the world. What all these clauses have in common is that they allow other fire safety measures to be lowered or eliminated in buildings protected with approved sprinkler systems.

Most of these clauses allow lowering of fire resistance ratings, e.g. from 30/30/30 to 15/15/15, however in some cases they allow the removal of fire resistance rating altogether. The other approaches which also qualify as sprinkler trade offs are those where the maximum allowable size of a firecell is increased, or the maximum escape path lengths are increased. All of these approaches make the structure cheaper (if sprinklers have been included already) and give the designer more flexibility in developing a design that will conform to the approved documents.

In New Zealand a sprinkler system conforming to NZS 4541 or NZS 4515 can be utilised to allow lowered passive protection standards throughout a building.

3.1. Trade Off Justification

There is an argument presented that sprinkler trade offs cannot be justified. It is suggested by some people that because the sprinkler success rate is so high in this country when a sprinkler system is present in a building, no passive protection is required at all. A sprinkler system will confine the fire to the object of origin and any passive systems present will not be threatened.

If we are to consider the possibility of sprinkler failure we must assume the sprinkler system fails completely. Therefore the original level of passive protection will be required to ensure the safety of occupants, the environment, Fire Service staff and other peoples property. This will be only 0.54%[i] of the time but on these occasions the level of passive protection described in the approved documents will be required as the fire growth rate has not been altered.

How do trade offs fit in to this scenario? It is a fact fire engineering is an inexact science, the large number of assumed variables and the unpredictable nature of fire make calculating the exact progress of a fire impossible. Also the consequences of fire are so great that all fire designs carry a factor of safety usually ranging from 1.5 to 3. In the rare event of a sprinkler failure it would be possible to reduce this factor, as the probability of this event occurring is so low.

If the factor of safety is reduced to between 1 and 2 we can reduce the design ratings of passive systems by 33-50% while still retaining a safe design in the event of a sprinkler failure. Although this lowered passive rating is not as capable of dealing with factors beyond the scope of the design, if the original design is sound we must assume the building will still be safe.

3.2. Determining Correct Factors of Safety

If this method is to be used to justify trade offs the original range of safety factors used to develop the approved documents must be considered.

Presently a BIA working group is considering the limits of tenability and recently made the comment below.

> *"The working group has not yet reached agreement on where minimum safety factors should be set in the proposed Verification Method, and comment is sought from interested parties. The expected range of minimum safety factors is between 1.5 and 2.5 with the possibility that different occupancies will be subject to different values."*[iii]

If the working group does select this range of factors of safety within its calculations and the standard level of trade off remains at the present level of 50% once the trade offs have been applied we would expect the factors of safety to be reduced to between 0.75 and 1.25 and some designs may be unsafe in the rare event of a sprinkler failure.

It would be hoped the areas that are traded off have the larger safety factors (between 2 and 2.5) or be in areas not critical to life safety, otherwise life safety will be threatened. If the sprinkler system fails, to maintain safety in critical areas where the safety factor is small the logical level of trade off may be no more than a 33% reduction in passive protection.

4. Literature Review

4.1. Trade Off Analysis

Although the effects of trade offs are not well understood some efforts have been made to quantify the risks involved in trading between fire protection measures and determining the correct level of trade off. The most successful work of this type has been carried out with a statistical study completed in the U.K. by G. Ramachandran and risk analysis and delphi studies completed in Canada by T.Z Harmathy.

4.1.1. Extreme Value Theory

In the early 1980's research was being carried out in England to determine the correct value for trade offs. G. Ramachandran[iv] has used the properties of extreme order statistics to compare cases with and without sprinklers and with varying levels of passive protection.

Method

For events such as fires where a large amount of data is available but it is not economical to collect and analyse all this data extreme value theory may be used. For assessing the value of fire protection measures loss data is generally only freely available for the most significant events. For example, it was found during an analysis of the textile industry in England the 10% of fires that produced the highest loss were responsible for 50% of the total loss. Once the data from these fires are collected and arranged in order of descending loss a parent distribution may be applied.

Once this parent distribution has been developed it is possible to predict the largest loss during a time period (usually a year) and the total loss over this same period.

These results are usually presented on a chart with number of fires against expected loss, an example is shown in Figure 2.

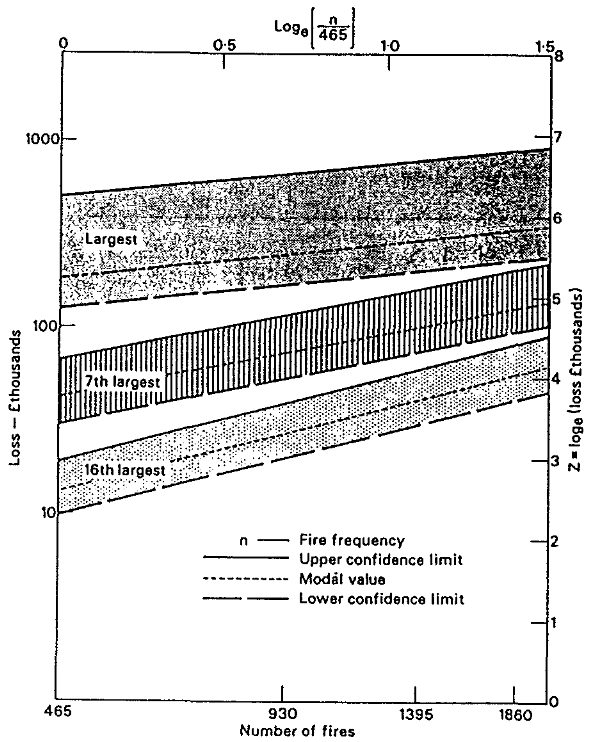

Figure 2; Results of extreme value study

By applying this method twice, to structures protected purely passively and again to buildings with sprinklers and lowered passive protection it will be possible to compare the two results to determine which method produces the lowest dollar loss. If the method is conducted again replacing dollar loss with lives lost a comparison could be made to determine the value of these systems to life safety.

Results

Although it proved impossible to conduct this analysis in New Zealand due to the scarcity of available data, a similar analysis has been conducted on textile industry buildings in the U.K.

Ramachandran divided the buildings into four groups, sprinklered, further divided into high and low fire resistance, and unsprinklered also further divided into high and low fire resistance. By using loss data made available by the insurance community, presented in Table 1, he compared the dollar loss as a result of fires in these buildings.

		Floor Area (square feet)	
		100 000	1 000 000
Sprinklered	High fire resistance	37 900	322 800
	Low fire resistance	29 600	268 600
Non Sprinklered	High fire resistance	48 300	281 900
	Low fire resistance	56 700	624 900

Table 1; Total fire cost for extreme value analysis

The results here that are relevant to the trade off problem is the fact that losses in sprinklered buildings are lower than those in non sprinklered buildings whether the levels of passive protection in the structure are high or low.

Ramachandran used these results to conclude...

> *"If for some reason it is decided not to install sprinklers in a large multi-storey building it would be more economical (less total cost) to make the building highly fire resistant. However, if sprinklers are to be installed, it is not economical to spend money to increase the fire resistance of the structure as well."*

It is well known that New Zealand has a sprinkler record well above the record in the U.K. This is due to a number of factors including the extensive testing and maintenance procedures we have in place and the high water pressures we typically experience in this country. It could be concluded therefore that if this method were to be applied to a group of buildings in this country the outcome here would be even more favourable towards trade offs.

4.1.2. Risk Analysis

In the late 80's Harmathy[v] conducted a set of risk and delphi studies concerning the balancing of fire protection measures to achieve the greatest possible protection for a given cost.

This work concluded in the production of the following equation.

$$L = NP_P l_P + N(1-P_P)[P_{FSC} l_{FSC} + P_{FSD} l_{FSD} + P_{FN} l_{FN}]$$

Where

L = fire loss (human + property) expectation (dollars per year per square metre floor area)

N = expected number of fire incidents (per year per square metre of floor area)

P_P = probability that, given ignition, the fire will not reach flashover

P_{FN} = probability that, given flashover, the fire will not spread to other compartments

P_{FSD} = probability that, given flashover, the fire will spread to other compartments by destruction.

P_{FSC} = probability that, given flashover, the fire will spread to other compartments by convection (by the advance of flames and hot gases)

l_P = average loss (human + property) resulting from fires that do not reach flashover (dollars per incident)

l_{FN} = average loss (human + property) resulting from post flashover fires that do not spread (dollars per incident)

l_{FSD} = average loss (human + property) resulting from post flashover fires that spread by destruction (dollars per incident)

l_{FSC} = average loss (human + property) resulting from post flashover fires that spread by convection (dollars per incident)

Harmathy then completed this equation with data from fire losses in Canada and a combination of the results of a Delphi study[2] and historical data to determine the required probabilities.

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[2] A Delphi study draws from the expertise of group experts in any field. Although these experts never meet and the study is completed by mail their opinions, normally on probabilities, are compared and if they fall within statistical bounds are accepted. If they fail to converge an iterative process is undertaken with the participants asked to supply a new opinion based upon the previous findings. If the results still fail to converge no result is obtained.

Information on Expected Losses

NFIRS data was analysed to produce the data shown in Table 2. Harmathy noted that although there was no factual basis to the assumption that fires spread by destruction caused more property damage than fires spread by convection $5 000 was added to this figure to denote the barrier being destroyed completely.

Value for human life was taken as $\$0.558 \times 10^6$ and cost for injury as 0.022×10^6, these being the figures reported in the Reugg-Fuller study[vi]. Harmathy commented these were well accepted figures in Canada in 1985 but seem much lower than figures accepted in New Zealand today.

Types of Loss	Losses in fires that do not reach flashover ($ per incident)	Losses in fires that grow beyond flashover ($ per incident)		
		Non- spreading fires	Fire spread by destruction	Fire spread by convection
Property Loss	692	5 696	43 698	38 698
Death	993	6 696	17 744	17 744
Injury	448	1 384	2 248	2 248
	$l_P = 2\ 173$	$l_{FN} = 13\ 776$	$l_{FSD} = 63\ 690$	$l_{FSC} = 58\ 690$

Table 2; Expected loss from fire (per m² floor area)

Information on Probabilities

Table 3 shows how Harmathy interpreted the available NFIRS data to place all of the available data into three categories.

As Interpreted by Harmathy	As Classified by NFIRS Data	Number of Fires	Total
(Given Ignition)	Fires confined to object	95 558	
No flashover	Fires confined to part of room	36 297	
	75% of fires confined to room	21 731	
	Fires undetermined/not reported	61 421	
		215 007	215 007
(Given Flashover)	25% of fires confined to part of room	7 243	
No spread	Fires confined to compartment	1 699	
	80% of fires confined to floor	6 660	
		15 602	15 602
(Given Flashover)	20% of fires contained to floor	1 665	
Spread	Confined to structure	35 659	
	Extended beyond structure	5 712	
		43 036	43 036
			273 036

Table 3: Interpretation of Fire Spread Data

This data indicated 78.7% of fires would not reach flashover and would not spread beyond the room of origin, 5.7% of fires would reach flashover and also would not spread. The final 15.6% of fires would reach flashover and spread from the room of origin by destruction of the separating (F rated) elements or spread around fire rated elements through doors or other openings.

Harmathy then used these probabilities and expected loss values to determine expected losses for various building types with varying levels of protection. Two examples of interest to this study are reproduced in Table 4 and Table 5.

	Reference: conditions (minimum to meet code)	Buildings Fire Resistance Increased (P_{FSD} lowered from 10% to 5%)	Building Equipped with Sprinklers
P_P (no flashover)	0.837	0.837	1.00
P_{FN} (no spread)	0.402	0.402	0.611
Expected Loss ($/year/m^2 floor area)	$0.208	$0.207	$0.087

Table 4; Results of Harmathy's Analysis (Office Building)

	Reference: conditions (minimum to meet code)	Buildings Fire Resistance Increased (P_{FSD} lowered from 10% to 5%)	Building Equipped with Sprinklers
P_P (no flashover)	0.787	0.787	1.00
P_{FN} (no spread)	0.350	0.350	0.656
Expected Loss ($/year/m^2 floor area)	$0.545	$0.542	$0.171

Table 5; Results of Harmathy's Analysis (Apartment Building)

As we can see from these two tables the increase of fire resistance to contain the fire did not give any benefit to the building owner, the installation of sprinklers however did provide great benefits. It could be concluded therefore that if sprinklers were to be added to the base case and the passive protection lowered there would still be a net gain for the owner of the property.

At the conclusion of his study Harmathy noted.

1. *With basic low-rise buildings the optimum fire safety situation can be achieved with sprinklers, which will prevent a fire from reaching the flashover stage.*
2. *Case I indicates the futility of trying to improve fire safety by increasing the fire resistance requirements.*

The first conclusion is obvious the second, however, does not seem as self evident. Harmathy's second conclusion was based on his finding that fire spread (in post flashover fires) in the majority of cases was around the passive protection system and therefore the rating of the system had no effect on fire spread. He concluded the level of this protection is only of interest when the firecells were extremely well designed, constructed and maintained.

4.2. Fire Tests

From time to time fire tests are completed either by design or coincidence that relate directly to the trade off problem. A selection of the most significant are presented below.

4.2.1. 140 Williams Street

Tests were undertaken in 1990 on a representative corner portion of an existing 40-storey building situated in Melbourne.[vii]

The building in question was due to be refurbished and by law the existing asbestos insulation on the beams had to be removed. The tests were conducted to determine if the existing level of fire protection in the building (even though it did not meet the Building Code of Australia) was acceptable. The major deviations from the building code requirements were the lack of passive protection on the beams and floorslabs and the extra light hazard sprinkler system.

The stated goals of the tests were:

1. *Observe the nature, duration and intensity of fires generated by the contents and enclosure of offices typical of those in the prototype building.*
2. *Observe and evaluate the influence of the resulting fires on the unprotected composite slab and structural steelwork framing.*
3. *Observe the effectiveness of the extra light hazard sprinkler system for fires in the small office and open plan office areas of the building, and*
4. *Obtain data for use in the risk assessments to be conducted on the building.*

A fire was started in a waste paper bin in a small office opening into the open plan office area. At 6 minutes the windows began to break and the fire spread to the open plan office area. The fire then began to subside and four more fires were lit in the open plan area to accelerate the fire growth. 118 minutes after ignition the fire was beginning to subside and the fire was extinguished at 130 minutes.

There were no signs of distress or damage, such as permanent buckling or distortion to the structure of the building after the fire, and an inspection revealed no visible damage to the structural members.

The maximum beam deflection of span/73 was recorded during the fire but approximately half of this deflection was recovered once the structure had cooled. The maximum recorded steel temperature was 650°C.

4.2.2. Collins Street

The Collins Street tests were conducted in the same enclosure used for the Williams Street tests. The purpose of the test was to collect steel and air temperatures under real fire conditions in a realistic office situation.[vii]

The fire was started in a waste paper basket and allowed to burn out naturally, the peak air temperature was recorded as 1163°C near the ceiling.

The main conclusions from the tests were...

1. *External columns without passive fire protection located close to windows performed satisfactorily.*
2. *Columns without passive protection located within the enclosure required only nominal fire protection (provided by thin steel sheeting) to keep their temperatures below 500°C.*

4.2.3. 1990 Broadgate Fire

In 1990 a fire occurred on the first floor (second storey) of a 14 floor office building under construction in London.[viii] The fire started in a sub contractors office on a floor where most beams and no columns carried any passive protection. Quickly this fire grew to a fully developed ventilation limited fire.

Maximum temperatures during the fire were estimated as 540°C at the bolts and 650°C in the steelwork.

The damage to the structure during the fire was

1. distortion of some floor trusses
2. distortion of some universal beams near the supports
3. local buckling and shortening of five of the lighter columns by up to 100mm

Despite all this damage the structure remained stable and the damage was repaired quickly.

4.2.4. Report of Thomas et al

Thomas et al. presented a summary of 42 fires in multi-storey buildings, of these 18 were in steel framed buildings[viii]. All of these buildings contained some level of passive protection on steel structural members.

All of the fires detailed involved fully developed fires, the conclusions were...

1. *In the majority of cases, no post fire distortion of the structural frame was recorded nor was distortion noted during the fire.*
2. *In one case large quantities of passive protection was removed from the beams before the fire. Smaller secondary beams suffered some permanent deflection and local buckling, shear failure of some bolts was also noted. Despite this there was no local or regional loss of structural integrity.*

3. *In a fire in New York in 1993 a similar pattern was noted where secondary beams failed and local instability resulted, no loss of floorslab integrity or overall stability was found.*
4. *In two other cases minor buckling and in one case connection failure was noted, in none of these cases did instability result.*

4.2.5. Conclusions

In all of these situations the required standard of passive protection on structural members were compromised either by accident or design. However, none of these cases required any major work on the structure.

This would indicate the requirements for passive protection on structural elements might be placed at a conservative level to protect structures from very large fires. If the safety factors were to be lowered the structure would still be safe although it would be less well prepared for unpredicted large fires.

The standards used in New Zealand to protect structural elements place the required ratings at approximately the same level as these cases overseas, therefore we could assume we have the same safety levels built into our structures.

One item of interest is that all of the detailed reports of fires were in steel framed buildings. It is assumed the behaviour of other types of buildings would be different and it would be prudent for a reasonable factor of safety to remain in place for non-steel framed buildings until more data is collected on their behaviour in fire.

4.3. Report of Buettner

While all this work points to the fact trade offs improve life safety and property protection there are other opinions. In 1980 Buettner[ix] published a paper indicating sprinkler trade offs should be applied with caution for the following reasons...

- *Sprinkler proponents claim that many fire deaths could have been prevented if sprinklers had existed. However many other systems, such as smoke detectors, might have been equally or more effective as they operate earlier.*
- *In earthquake zones, statistics show that when structures perform well sprinkler systems remain intact. Unfortunately earthquakes often destroy the water mains that supply the sprinkler systems. Again sprinklers without water are just a collection of useless pipes.*
- *Arson is the fastest growing crime in the United States. Arsonists, spurred by motives of revenge, vandalism, and insurance fraud, will prevent sprinklers from working.*
- *Many building fires are accompanied by or as result from explosions that break waterlines, rendering sprinkler systems inoperative.*

Mainly due to the high rate of sprinkler failure in America (which he reported as 43%) he concluded...

- *Building structures should be highly resistive to fire and should be designed to minimise the possibility of structural failure during a fire. This is essential not only for occupants but also for fire-fighters.*
- *Compartmentation is a proven method of providing life safety for building occupants. Compartmentation (in other than small buildings) should include enclosing each storey, stairwell, elevator and utility shafts, and should provide at least two compartments separated by self closing doors or dampers.*
- *Automatic sprinkler systems must be required in hazardous areas, particularly where combustible contents exist. However, the structural integrity or life safety aspects must not be impaired. Sprinklers are simply not effective enough to justify using them alone in a life safety system. If sprinklers fail to control a fire, the building is no better off than if the sprinklers were not present. All it takes for failure is one closed valve.*

It should be noted that the success rate of sprinklers in this country is much higher than those quoted by Buettner for America. Therefore the applicability of this study to New Zealand's conditions may be questioned.

Despite these drawbacks the report does draw attention to various important facts such as the potential for sprinkler failure and the dangers of natural disaster that must be investigated further.

5. Building Code Trade Off Clauses

5.1. *History/Origin of Clauses*

5.1.1. NZS 1900 Chapter 5

Prior to the introduction of the New Zealand Building Code, Chapter 5 of the New Zealand Standard NZS 1900[x] regulated fire safety in New Zealand. NZS 1900 Chapter 5 was originally a model bylaw but it was made mandatory in the early 1970's and progressively updated until replaced by the New Zealand Building Code in 1992.

Sprinkler trade offs were first introduced into NZS 1900 in July 1978 when "additional credits for automatic sprinkler systems" were first allowed. These clauses were described in the foreword to later additions by...

> *"1. Major changes were introduced by Amendment 12 (1978), especially with the insertion of Table 1A, which permitted lowering of "types of construction" required where sprinkler protection is provided, thus enabling more extensive use of timber structural elements... "*

These trade offs are listed in the Appendix 1.

As stated in the foreword the major addition to the standard was an additional table supplementing Table 1 "Maximum allowable areas, number of storeys and minimum types of construction". Table 1A "Fire Compartments with Sprinklers" allowed, depending on fire risk group, either lowered fire resistance ratings on partitions or increased maximum firecell area.

By the time it was replaced NZS 1900 carried trade offs in the following areas[xi]...

- Increased compartment area
- Larger window openings (with drenchers)
- Reduced fire resistance ratings of exterior walls
- Saving in design of portal frames (not required to stand alone)
- Larger fire door openings
- Increased building height
- Combined exitways

5.1.2. New Zealand Building Code

The New Zealand Building Code[xii] was introduced in early 1992 and replaced the fire safety provisions in NZS 1900 Chapter 5.

As early as 1970's it was proposed to replace NZS 1900 but various problems with the development of the new standard (DZ 4226) meant by the mid 1980's little progress had been made. In an effort to speed up progress a new group was formed that eventually produced the Building Code that is now in place.

Early in the development of the Building Code a decision was taken to leave the protection of property to the owner of that property and only safeguard life (of both the occupants and the Fire Service), the environment and other persons property. This decision enabled the new documents to be written in a form that was much easier to use and enforce.

The negative effect of this was that by not enforcing property protection the economic situation of the country could suffer. Property lost in a fire is entered as a debit against New Zealand's GDP (Gross Domestic Product[3]). This means if New Zealand were to suffer a large property loss from fire in one year this would be equivalent to a lowering of the international wool or meat prices. Therefore property

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[3] A countries GDP is a measure of its overall economic wellbeing and is widely used to "rank" the status of countries

protection from fire could be seen in the same light as energy conservation or manufacturing efficiency - benefits are not only gained by the immediate benefactor (the property owner in this case) by the country as a whole. However, it was decided the incentive of reducing the immediate loss to a building owner from fire would be enough to ensure the building owner would ensure property losses from fire remained at a satisfactory level.

Eight trade off clauses were present at the introduction of the new Building Code.

Four of these clauses allowed areas of passive protection to be lowered where sprinklers where present and the remaining four allowing the total removal of some passive protection. Although it is unclear exactly how the clauses where developed and justified it is assumed they where largely influenced by the provisions in DZ 4226 and overseas building codes which made extensive use of trade off clauses at the time.

5.2. Clauses in Question

The clauses presently in the Approved Documents are shown in Appendix 1 these clauses when applied with the allowances in the B tables constitute the trade offs presently in allowed in the approved documents. Generally these clauses allow a 50% discount in passive systems, however two clauses allow for the total removal of some passive systems.

5.3. Effect of Clauses

Often building owners will opt to include a sprinkler system in the design of a new building where they are not otherwise required by the approved documents, they will be added to increase property protection and to lower insurance premiums for the building. When sprinklers are included in a building, the safety of occupants of that building and the safety of adjacent properties is greatly improved.

To offset this increased level of protection in the building the safety factors in other areas may be reduced. This may lead to lowered firecell ratings, minimum firecell sizes, and lowering of other passive restrictions.

In most cases when sprinklers fail we know they usually fail completely and at best restrict the fire growth for a limited time. In situations such as these it could be argued the original levels of passive safety will be required to ensure life safety. However in the development of the approved documents it was determined that if the sprinkler system should fail the lowered levels of passive protection will still provide a minimum level of life safety.

Two cases allow the total removal of passive systems; Clause 3.7.3 allows a firecell area in a single storey building to be unlimited and Clause 5.5.3 allows the removal of smokecells around shafts (except in purpose groups SC and SD). If clauses such as these allow the total removal of passive systems one of two situations must be occurring, either the passive system was not required in the first place and if the sprinkler system fails the structure will still meet all its design requirements, or the passive system was required and the structure has been made unsafe with their removal.

6. F Ratings

F Ratings are applied to partitions within a building designed to prevent the spread of fire and smoke, the effect of these partitions is to divide the building into separate firecells each insulated from the effects of fire in the next cell by a certain time.

F ratings apply to...

> *"Primary and secondary elements within a firecell, including walls and floors which are fire separations, together with their supporting elements within the same firecell."*

6.1. Building Code Requirements

F ratings are required in acceptable solutions to ensure the safety of occupants. The Building Code requires a building be constructed to...

1. Give people adequate time to reach a safe place without being overcome by the effects of fire
2. Give Fire Service personnel adequate time to undertake rescue operations

6.2. How the Approved Documents Meet these Criteria

To meet these requirements the approved documents require a building to be divided into firecells of various sizes and with various fire resistance ratings. The effect of this is to limit the speed with which a fire can spread through a structure providing extra time during which occupants and fire-fighters can safely move within the structure away from the firecells already affected by fire.

6.3. How Sprinkler Trade Offs Affect these Criteria

Where a sprinkler system is installed by the building owner (and not required by any other section of the approved documents) the F ratings required by the approved documents is lowered in some areas. The building owner has probably installed sprinklers to safeguard his property but their installation has also greatly increased the safe margin for life safety within the building. Therefore, it is reasoned the safety factors on any other protection features may be lowered.

It is known F ratings carry a safety factor of 1.5 to 2.5, if these ratings were to be reduced by 50% (as is most commonly seen in trade off clauses) we could expect the new safety factors to range from 0.75 to 1.25. We could now suggest that some of these clauses do not provide a satisfactory level of life safety.

We would hope that the areas that allow trade offs are the areas that the larger safety factors apply to and the design is still expected to be safe. However even in this case the safety factor is reduced to what could be considered to be a minimum level, any further reductions in required F ratings would have to be questioned.

7. S Ratings

S ratings are applied to buildings that can cause harm to other property in the event of a fire. The S rating ensures the building will remain stable and not threaten other structures on adjacent properties.

S ratings apply to...

a) *"Fire separations within firecells which require subdivision due to restrictions in floor area"*
b) *"Primary elements within a firecell which provide stability to an external wall not permitted to have 100% unprotected area"*
c) *"Secondary elements forming parts of an external wall which are not permitted to be unprotected areas"*
d) *"Any part of the floor system and structural frame designed to provide stability to the external wall when required by Paragraph 4.3."*
e) *"Fire separations, floors and supporting structures in car parking spaces within a building as required by Paragraphs 2.12.3 to 2.12.5"*

7.1. Building Code Requirements

The Building Code requires a structure to

1. Protect household units and other property from damage due to structural instability caused by fire.
2. Safeguard the environment from adverse effects caused by fire.

7.2. How the Approved Documents Meet these Criteria

To meet these requirements the approved documents ensure a building is structurally stable during a fire by specifying minimum fire ratings (or S ratings) for those structural elements deemed to be vital to the buildings design.

7.3. How Sprinkler Trade Offs Affect these Criteria

When sprinklers are added to a building the safety margin provided by the approved documents for structural stability is considerably increased due to the lowered temperatures and lowered expected size and duration of the fire. Thus it has been deemed acceptable to lower the factors of safety of the approved documents in these cases.

The fire tests already considered in this report indicate the required S factors have a large factor of safety and even when this rating is reduced by the removal of some passive protection the structure performs as required.

The reduction presently allowed in the approved documents is 50%, this reduction means that passive protection is commonly required on structural member to meet this stipulation although this protection is lighter and cheaper. If the allowances were to be reduced further the structural member itself could meet the S rating and no passive protection would be required.

The consequences of a structure failing due to fire would be large. The businesses within the building would be disrupted for a long time, other property would be damaged and the probability the fire would spread to an adjacent building would be greatly increased. Other factors such as the international attention this event would bring and the harm it could do to New Zealand's standing at the forefront of the fire safety community would be very hard to deal with.

For these reasons any further lowering of the S ratings allowed under the approved documents must be bought in to question and carefully investigated before changes are made.

8. Firecell Areas

8.1. Building Code Requirements

Area restrictions are required in the approved documents where S ratings are required for a structure. Although there is no clear objective within the Building Act or Building Code in limiting the firecell areas doing so will achieve several stated goals...

1. Protection of Fire Service personnel (by limiting the size of the fire)
2. Protection of the environment (by limiting the size of the fire and therefore the emission of toxic products)
3. Control the spread of fire (as required by the Building Act)

8.2. How the Approved Documents Meet these Criteria

The approved documents limit the firecell area in Clause 3.7. Firecells in buildings requiring S ratings are limited in size to limit the amount of fuel available to the fire and therefore the expected fire size.

8.3. How Sprinkler Trade Offs Affect these Criteria

When sprinklers are provided by the building owner in a single storey building Clause 3.7.3 allows unlimited firecell area. This allowance may result in a large amount of fuel being available to the fire.

Large single storey buildings are generally used as warehouses and it is in this type of occupancy that large property losses are most often experienced. An analysis of fire statistics has shown warehouse structures have 15% of fires in New Zealand but suffer 50% of the total losses. The mass of goods packed in high density, often in rack storage, provides a large fuel load to the fire and the lack of effective fire protection measures makes fire a real concern.

It is this type of building where sprinklers most often fail to achieve their objectives. Often sprinkler heads are high above the floor leading to delayed operation. Also if the goods are shrink wrapped in plastic the sprinkler system will be unable to wet down fuel adjacent to the fire and fire spread will be more rapid, even to the point where the sprinkler system may be overpowered. Another potential problem in this type of building is the high rack storage which may mean there are locations within the racks out of reach of the sprinkler system.

Despite all of these problems life safety is of no real concern in these types of buildings due to the ease of escape from such a building. In a typical open plan single storey warehouse there are many escapes around the building and no real obstacles from anywhere within the warehouse to these exits. Property protection, protection of Fire Service staff and protection of the environment, however are of real concern.

Despite all the problems with this type of structure sprinkler trade offs allow an unlimited floorspace where sprinklers are present. In the event of a sprinkler failure the large mass of available fuel would create a fire that would quickly grow and spread out of control through the building. By the time the Fire Service could respond to an alarm and set up to tackle the fire it would be difficult for them to fight the fire effectively and safely.

Usually the best result that could be achieved would be wetting down and protecting adjacent properties, in this situation the building and its entire contents would be a complete loss.

If trade offs had not been utilised firecell areas within the building would be limited to firecells of an area determined by the fuel type. Property losses would be limited as the rated partitions would constrain the fire to a size the Fire Service would be more able to control. Emissions to the environment would be limited and the fire would be less likely to spread to other properties. By partitioning the structure the building would comply better with the Building Act and the property of the owner would be protected from fire and smoke damage.

9. Escape Path Lengths

Escape path lengths are limited to ensure the occupants of a building can find an exit easily and quickly make their way to safety.

9.1. Building Code Requirements

The Building Code requires...

1. Give people adequate time to reach a safe place without being overcome by the effects of fire.
2. Give Fire Service personnel adequate time to undertake rescue operations.

9.2. How the Approved Documents Meet these Criteria

By limiting escape path lengths the approved documents ensure occupants within the structure are near a place of safety and can easily reach it and fire service staff can easily reach the seat of the fire.

9.3. How Sprinkler Trade Offs Affect these Criteria

Where a sprinkler system is installed escape path lengths may be increased by 50%, this will lead to a 50% increase in the time an occupant is exposed to the harmful effects of fire. Another effect is an increased time Fire Service staff will take to reach the seat of the fire, often travelling through smoke using breathing apparatus which has a limited air supply. In this situation the time a fire fighter has to actually fight the fire is reduced (as his/her travelling time increases) resulting in a higher probability of the fire spreading.

10. Overseas Codes

10.1. Overseas Building Code Equivalents

As part of the analysis of the sprinkler trade off clauses in the New Zealand Building Code it will be useful to compare these to the trade off clauses present in building codes from other countries.

A copy of the clauses used is presented in Appendix 1

10.1.1. F Ratings

F rating reductions in overseas codes are difficult to judge as the systems used by different countries used to separate firecells is so diverse. Reductions are offered in the United States and Canada.

10.1.2. S Ratings

New Zealand

50% reduction in requirements

Australia

No concessions

Canada

Structural members in top floor and roof can be constructed of heavy timber

Uniform Building Code

Type II, III and IV Buildings may have the 1 hour construction limit waived.

10.1.3. Escape Path Lengths

New Zealand

50% increase in open path lengths

Australia

No Concessions

Canada

Single egress paths from each room or suite may be increased to 25 m (up to 100% increase depending on hazard group)

Uniform Building Code

Pedestrian walkways may be up to 400 feet (33% increase)

10.1.4. Fire Compartment Size

New Zealand

Unlimited firecell area in single storey buildings

Australia

Firecell sizes (from Table C.2) may be exceeded up to a limit of 18 000 m^2 or 108 000 m^3 providing a sprinkler system and vehicle access meet acceptable standards. (125 - 500% increase depending on hazard group)

Canada

Area limits on baled combustible fibres may be doubled.

Maximum areas for rooms or suites (not in permanent dwellings) increased from 33-50% depending on Hazard Group.

Uniform Building Code

Firecell areas in single storey buildings may be tripled and in upper levels may be doubled.

10.2. Conclusions

From the brief outlines of overseas codes presented above it can be seen that in general New Zealand is generous in allowing trade offs.

In New Zealand we allow much greater concessions in the areas of structural stability and firecell sizes. Canada does allow a greater concession on path lengths but this only applies to few hazard groups.

11. Risk Analysis

11.1. Introduction

Trade off theory depends heavily on the effectiveness and reliability of the system. The system as it is referred to in this following analysis consists of any combination of passive and active sub-systems combined to protect a structure and its contents (including any occupants) from fire. Risk analysis can be applied to any system where each individual component contributes in some form to the probability that the system will perform its required function[xiii]. An accepted drawback of risk assessment is that it usually depends on the views and experiences of the person performing the analysis. To avoid this problem use has been made of as many sources as possible to try to reach a consensus opinion on the probability of each failure.

Reliability is defined as *"the probability of performing a specific function or mission"*[xiv]. As sprinkler systems are all built to the same standard their reliability can be accurately predicted from historical data. The reliability of passive systems, however, is more difficult to predict due to the factors already outlined.

Other events will heavily influence the systems effectiveness, the response of the fire service and the occupants of the building can heavily dictate whether a building is safe or not, as shown in Figure 3

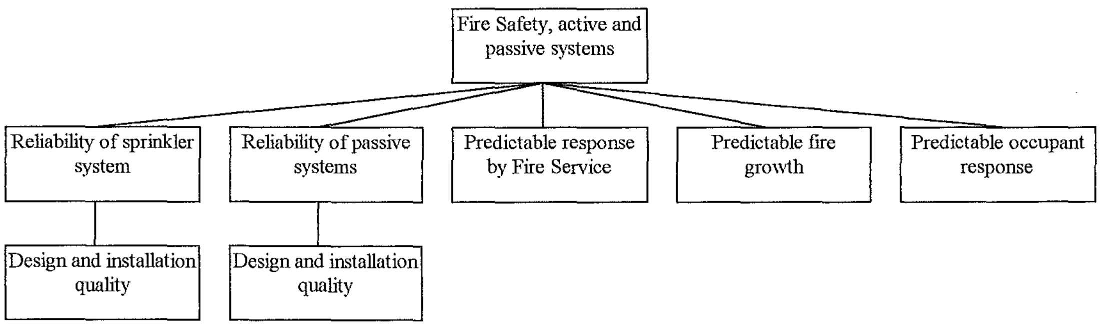

Figure 3; Factors in Reliability

As it is difficult to predict how these factors will influence the loss of life and property in a fire a method has to be developed for dealing with them.

Fire Service response can be utilised only where sprinklers are present as we can assume activation of the sprinkler system will automatically operate an alarm. When a sprinkler is not present we can not assume an alarm will be raised and therefore we will exclude the Fire Service from the resulting events.

Fire growth is more difficult to justify, different types of fire (smouldering, flaming explosions etc.) can lead to different responses and different failure modes in the systems under inspection. To account for this the analysis will be conducted considering a smouldering and flaming fire, other fires such as explosions should be dealt with separately wherever dangerous goods or other factors indicate this could be a problem.

11.2. Method

A risk assessment approach based on fault tree diagrams has been used in this study, this method consists of identifying the events that will lead to a failure in the system and then assigning probabilities to these events.

Probabilities on the reliability of sprinkler systems has been established from the history of sprinkler operation in New Zealand and Australia[i]. Information on the failures of passive systems has been sourced from various studies as indicated. Generally these figures are an average from different locations where these sources closely agree, otherwise attempts have been made to discover why the values differ and appropriate values selected.

11.3. Fault Tree Development

Two fault trees will be produced, considering cases with and without the trade off clauses being utilised.

11.3.1. Probabilities of Sprinkler System Effectiveness

Sprinkler system effectiveness and reliability can be easily determined from historic data widely available. Since the first sprinkler system was installed in New Zealand in 1889 reports have been required in every case of sprinkler activation. This has resulted in a large and accurate database, Maryatt[i] has interpreted this data producing the summary shown in Table 6

		Probability
Sprinkler Failure		0.03%
Sprinkler Operation	Sprinkers Fail to Control	0.54%
	Occupant Intervenes	16.15%
	Fire Service Intervenes	20.62%
	Sprinklers Extinguish	62.66%

Table 6; Sprinkler Operation Probabilities

These figures indicate that in the future (if the sprinkler standard NZS 4541 remains largely unchanged), we could expect that in 99.43% of cases the fire would be confined to the object of origin. In the remainder of cases there is no information on how quickly the fire grew despite the application of water from the sprinkler system, therefore we must assume the fire grew as if no sprinkler system was present at all.

11.3.2. Probabilities of Passive System Effectiveness

The reliability of passive systems is more difficult to determine due to the lack of reporting of the mode of spread through buildings. Various Delphi studies have been completed around the world to try to determine how fires spread and how passive systems react when in place.

A survey done in central Wellington in the late eighties[xv] found that over 24% of fire stop doors in office blocks were either removed or wedged open. This means the integrity of the firecell has been destroyed, effectively the firecell rating has become 0 minutes. Of the remaining 76% of fires we can not tell if the fires were extinguished immediately, contained by the passive system or spread past the passive system either by destruction of it or through other openings.

These figures agree with the findings of Harmathy[v] who conducted a Delphi study and found 74.6% of fires did not reach flashover, they either did not spread from the object of origin or were extinguished by sprinklers or occupants. Of the fires that did reach flashover Harmathy predicted between 5 and 10% of fires would spread through the fire barrier by destruction

Narayanan et al published the data provided by the FIRS database (maintained by the New Zealand Fire Service). By using the same method as Harmathy it is then possible to reduce the flame spread data to the data shown below.

Bukowski is presently producing a report for the WPI[xvi] part of which was a Delphi study which concluded 74.5% of fires do not spread from the room of origin.

	No Flashover	Flashover		
		No Spread	Spread by Convection	Spread by Destruction
Narayanan et al. (1996)	80.54	7	12.44	
Fire Service (late 80's)	-	-	24	-
Harmathy (1989)	74.63	-	25.28	0.09
Bukowski (1982)	74.5		25.5	

Table 7; Performance of Passive Systems

The one variable not presented in these results is what size the fire reaches before it becomes part of the reporting process. It may be for this reason the figures for fire spread presented by Narayanan are low compared to the other studies, fires of a small size may have been included in the New Zealand data to produce results skewed towards non flashover and non-fire spread.

To attempt to simulate the trade off clauses being utilised passive system effectiveness changes from situation to situation. For example where there are no sprinklers present the rating of the element will be double what it is when sprinklers are present, therefore we would expect less failures through the system. It is for this reason spread through the system is lowered to 5% in the passive systems example.

11.4. Results

If all of these probabilities are considered and all of the possible failures of the system determined the flow charts in Figure 4 and Figure 5 will be produced.

Figure 4 shows all the possible outcomes and their final probabilities (shown in brackets) for a system utilising the trade off clauses.

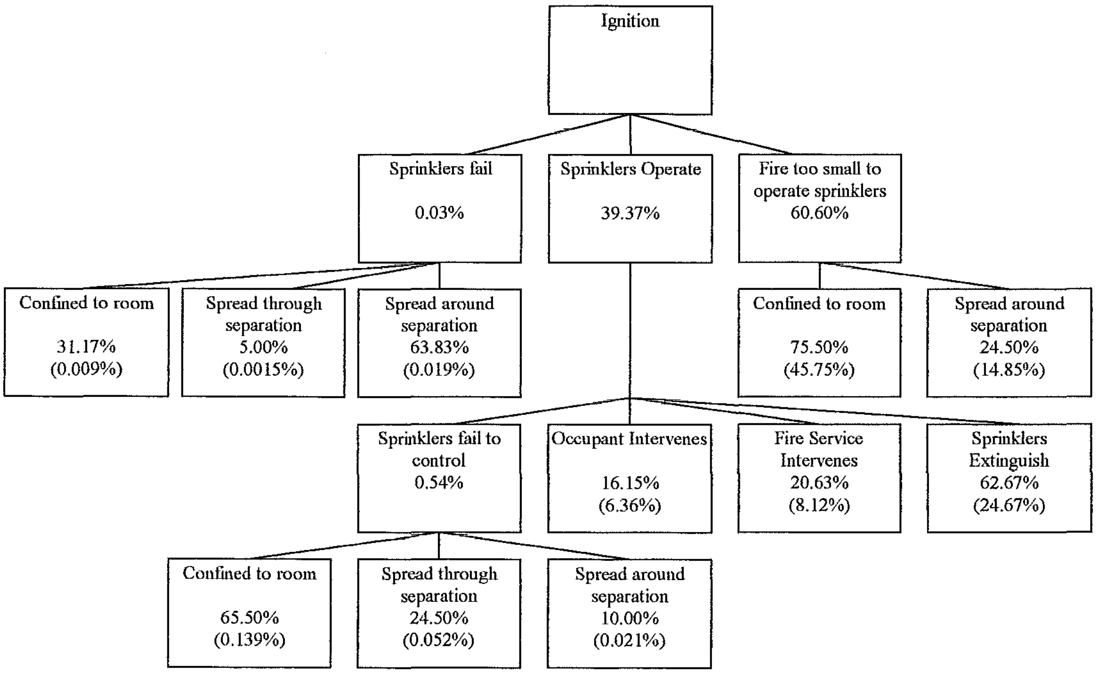

Figure 4; Risk analysis results - trade offs used

Of interest to this problem is the high number of fires that spread through openings or are confined to the room. Under 1% of fires spread through a passively rated structure indicating efforts made to seal doors and other openings against fire are not sufficient.

Figure 5 shows similar information for the case where sprinklers are not installed.

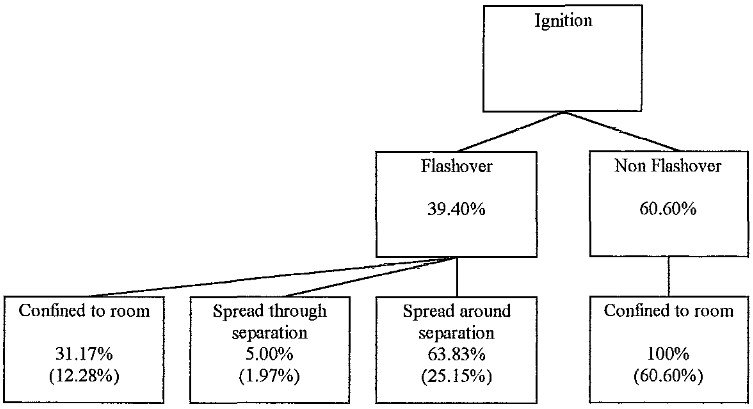

Figure 5; Risk analysis results - passive protection only

Once again the amount of fire spread around the passive system is disproportionately large.

If the possible outcomes that could be a threat to life safety are examined and compared between the two scenarios it should be possible to determine which is safer.

Where sprinklers are present the only unsafe situation will occur when sprinklers fail to operate or fail to control a fire and then the fire spreads around a passive system (which would be expected to be much quicker). Where no sprinkler system is present the life safety limit can be assumed to be once again in situations where the fire spreads by convection.

Therefore where there is no sprinkler system present an unsafe situation might arise 25.5% of the time and when a sprinkler system is present this figure is reduced to 0.04%. Obviously the building that has utilised the trade off clauses is much safer for the occupants and presumably for the fire service as well.

12. Risk of Natural Disaster

It is known sprinkler systems are most susceptible to problems in the water supply or at the point where the water supply enters the building. In the event of a natural disaster (the most obvious in New Zealand being an earthquake) this water supply pressure may be lowered or cut off completely, in this case extra demands will be placed on the already lowered level of passive protection. Again, the question arises "does this lowered level of protection provide a minimum level of life safety?"

A further complication to this argument is that passive systems within the structure may be damaged by the same forces that threaten the water supply. This effect was noted in the recent Kobe and Northridge earthquakes. Now it may be argued an increased factor of safety may be required within the structure to offset any damage to these systems. Another factor is the lack of assistance that could be provided by the Fire Service in these situations, roads will be blocked and there will be many alarms to answer. Even if the Fire Service can respond to the alarm the response time will be greatly reduced and the fire size upon arrival will be much larger. Can it be justified in reducing the factors of safety in passive systems under these circumstances?

The chances of an earthquake large enough to threaten the buildings limit state (i.e. an event that will necessitate extensive inspection and reinstatement of non-structural and structural systems) is considered to be 10% in 50 years[xvii]. In an earthquake of this magnitude we could assume there would be a major disruption to services causing the failure of the active systems. In an earthquake of this magnitude it is also likely there would be some level of damage to the F rated elements within the structure.

The potential level of damage to the F rated elements is difficult to determine due to the unpredictable nature of natural events, however it should be noted that it is in events such as these that the factor of safety applied to passive systems come in to play and ensure life safety. If these factors of safety are lowered is life safety still assured in a situation such as this?

13. Property Protection

In the analysis of the trade off clauses allowed within the present approved documents we have established how sprinkler trade offs affect life safety within a structure but what effect does lowered passive protection have on property protection?

13.1. Water Damage

One of the most common charges laid against sprinkler systems is that the water damage to the contents of a space may be very expensive.

It is generally accepted that sprinkler systems apply 10% of water that would be applied by the Fire Service in dealing with a similar fire. This is due to the fact that sprinklers operate much quicker than the Fire Service can respond to an alarm and apply water directly to the base of the fire. This means the fire is extinguished while it is still small and less water is required. To apply water to the fire The Fire Service must usually use hose streams from outside the building. It is estimated only 50%[xviii] of the water used by the Fire Service reaches the vicinity of the fire, the rest fails to enter the building through openings or is blown away by wind or thermal currents.

Therefore in the event of a fire sprinkler systems will produce much less water damage than the Fire Service would in dealing with the same fire.

We must also consider the fact that sprinklers do cause damage by leakage and false alarms if there is no fire. In the period from 1948 to 1967 in Australia and New Zealand insurance claims for this type of damage averaged $70,000[i] per annum. Over the same period sprinklers were estimated to have saved $9,414,500 per annum in property damage indicating the damage caused by false activations is more than offset by the savings made in the event of a fire.

13.2. Smoke Damage

Smoke damage is one of the biggest costs in small to medium sized fires. Smoke damage can be limited by either limiting the travel of the smoke or by quickly limiting the size or extinguishing the fire to limit the amount of smoke produced. Passive protection will achieve the first goal and active protection will achieve the second.

13.2.1. Flaming Fires

It is expected a sprinkler head directly above a fire in a 3m ceiling space will activate between 5 and 10 minutes[xix] after ignition when the fire size would be expected to be 10-15kW. Quick response heads can limit this activation to 2 to 5 minutes where the fire would be expected to be 5-10kW. The response of the fire to the application of water is difficult to predict. We know that in 99.47% of cases the fire will not grow any further than the size at which the sprinklers activated and in a large majority of cases will begin to reduce in size and eventually be extinguished.

The time to extinguishment varies widely depending on fuel, ventilation and many other factors. Models have been produced from tests completed on crib fires that indicate sprinklers can reliably halve the size of a fire in 45 seconds with a flow rate of 0.205mm/s[xx]. These fires are optimum cases with the sprinkler head directly above the fire and no obstructions as would be the case if the fire were under a desk.

It can be seen that it will be many minutes before the fire is extinguished if at all. During this time the fire is producing smoke that will travel through the structure as far as the passive systems will allow.

Although passive systems will not slow the generation of this smoke the travel of this smoke can be contained to a specific space and no losses will be experienced in firecells remote from the firecell of origin.

This is of interest when we consider clauses within the approved documents that allow the removal of smoke barriers. Clause 3.7.3 allows a firecell area in a single storey building to be unlimited and Clause 5.5.3 allows the removal of smokecells around shafts (except in purpose groups SC and SD).

Both of these clauses will allow much greater travel to the smoke produced by a fire, even though a much smaller quantity of smoke will be produced. This could lead to a much greater loss of property when the trade off clauses have been utilised and firecell areas have been increased.

13.2.2. Smouldering Fires

A special case, which may lead to situations that are hazardous to both life and health, is the smouldering fire. The most commonly recognised example of smouldering combustion is that of a cigarette, an accurate definition of this type of combustion is...

> *"...a slow low temperature flameless form of combustion, sustained by the heat evolved when oxygen directly attacks the surface of a condensed phase fuel."*[xxi]

Smouldering fires produce a different combination of products than a full flaming fire, depending on the fuel, products of smouldering fires are generally more toxic than those of flaming fires.

Another problem with smouldering fires is that they burn at a lower temperature producing a less well defined plume. The effect of this on sprinkler systems is that a smouldering fire is less likely to activate a sprinkler system as quickly as a flaming fire (if at all) due to the lowered temperatures. This would lead to a smouldering fire growing out of control producing large amounts of very toxic smoke that will spread through the structure.

Smoke damage in a space (to the contents and linings of that space) is limited by the size of this space. Obviously if a large open warehouse is divided into four sections by smoke curtains the damage due to smoke in the event of a small fire is likely to be one fourth of what it could be if the space is well designed and maintained.

13.3. Conclusions

In areas where valuable goods are stored (museums for example) or large quantities of goods are present (such as a warehouse) it would be prudent for a building owner not to take advantage of the trade offs presently allowed in the approved documents. By restricting the travel of smoke property savings may be large in the event of a fire. This is of course at the discretion of the owner of the property but to make this decision they must be properly informed. Fire engineers should bear this in mind when briefing building owners on the risk of fire in his/her property.

14. Economic Analysis

14.1. Introduction

The application of trade off clauses in a structure will lead to differing costs on the project. The cost of introducing a sprinkler system must be weighed against the reduced cost of passive protection and many other factors such as reduced insurance premiums. Benefits will also apply to the system which best protects life and property.

By the use of a simple cost benefit analysis it will be possible to determine if the use of the sprinkler trade off clauses will be prohibitively expensive for a designer.

14.2. Cost Benefit Method

If a cost benefit analysis of the application of sprinkler trade off clauses is to be useful it must examine all the factors involved in the cost and benefit streams of sprinkler and passive system installations.

The analysis will be conducted by considering a building not applying the trade off measures as a base case and considering the costs and benefits of applying the trade off clauses to the building.

14.2.1. Cases Examined

Two cases are to be examined in this analysis, an office building of seven floors and a large open warehouse.

These cases were chosen to display trade offs being displayed in different ways, the main advantage in the warehouse will be the concession in firecell areas that will mean no internal divisions are required. The main advantage in the office building will be the reduction in F rating requirements on internal divisions and S ratings on structural elements.

14.2.2. Parameters

Two general parameters are required before a cost benefit analysis can be completed.

The time period used for this analysis was chosen as 30 years. This value was selected to indicate the expected lifespan of a sprinkler system. The lifespan of a building will probably be greater than this but events such as a change of use or restyling mean over a period this long the building will probably be significantly altered resulting in the analysis no longer being applicable.

The discount rate is used to allow for inflation when considering on going costs such as maintenance and also for comparing costs in the future at different times. Cost Benefit studies applied to sprinklers generally use a value of 6%, therefore to allow comparison this value will be carried into this study.

14.3. Costs and Benefit Streams

14.3.1. Costs

The costs used in this analysis are obvious, there is the initial cost of installing the chosen protection system and the on going cost of inspection and maintenance of the system to assure proper operation.[xxii]

The costs of sprinkler and passive system installation are a one off cost that will be sourced from quantity surveyors. The cost of maintenance applies only to sprinkler systems where inspection and certification is required, this cost will be calculated using Uniform Present Worth as shown below.

$$UPW = A_O\left[\frac{1}{i}\left(1-\frac{1}{\left(1+i^n\right)}\right)\right]$$

Where...

A_O = recurring annual sum to be paid over a period of N years ($)
i = discount rate
n = expected lifetime of the system (years)
UPW = uniform present worth ($)

14.3.2. Benefits

Benefits are provided by the reduced losses in life, injury and property when the system acts as expected. Another benefit can be applied where a sprinkler system is installed, that of reduced insurance premiums. A benefit unique to trade offs is that of the lowered cost of passive systems.

Values for costs due to loss of life and injuries is the product of the probability of the event by the cost of the event. The value of human life and injuries is an emotive issue, most recent studies in New Zealand[xxiii] have placed this value at $800 000 for loss of life and $40 000 for injury.

14.3.3. Factors Not Included

In all cost benefit analysis not all areas can be covered due to the complexity and uncertainty associated with some of the cost and benefit streams that would result. In this particular study the streams not accounted are shown below...

Costs

1. **Interruptions to Business**: The costs of relocating the business and recommencing operations, also the costs of replacing lost records and computer files.

2. **Cost to Fire Service**: In a major fire the costs to the Fire Service may be large with the use of many appliances and staff members. This also covers the costs of injury of fire fighters undertaking their duties.
3. **Environmental Costs**: Although this is a goal of the Building Code it is difficult to put a dollar value on lowered emissions to the environment of smoke and toxic run off.
4. **Water Damage from False Activations and Leakage**: Water damage from the sprinkler system activating in error and leakage from the pipework or heads. Statistics indicate the probability of a sprinkler system activating when there is not a fire present is 1 in 16 million[i] and the probability of a quality fault in a sprinkler system leading to a leak is 1 in 60 million[xxiv]. Therefore the associated costs would be expected to be small enough to be considered negligible.

Benefits

1. **Flexibility in Escape Paths**. The benefit leading from increased escape paths may be great if it is possible to provide the structure with one less escape path. The benefit will depend on whether this is possible and the design of the building.

Before the results of the analysis are presented it should be noted this study may be conservative due to the present trend of increasing life and property safety that is expected to continue over the next 30 years. This is due to improved Fire Service performance due to improved techniques and technology and the design of new buildings which are becoming increasingly safe with respect to fire. These factors are impossible to calculate so we must presume loss rates remain as they are presently.

14.4. Case 1: Low Rise Office Building

The building considered in this section was a seven-storey office building of steel and concrete construction with a floor area of 400m^2. The ground floor was devoted to retail spaces and the upper floors were open plan office spaces. This type of building would be typical of many in New Zealand. At present sprinklers are not mandatory in this type of building so many would only be equipped with smoke or heat detectors and hand held fire fighting equipment.

14.4.1. Costs

The cost of a sprinkler system complying with NZS 4541 was estimated for the building outlined above. This gave a figure of $285 000, the cost of inspection and maintenance as required to comply with insurance council regulations is $2 350 per year giving a uniform present worth of $32 350. Thus, the sprinkler related costs for the 30 year period are $317 350.

		Cost ($)
Sprinkler Installation		285 000
Sprinkler maintenance		32 350
	total	317 350

Table 8; Costs of utilising trade offs

14.4.2. Benefits

A building as it has been described is occupied by purpose groups WL on the upper floors and CM on the ground floor. These types of occupancies require firecell ratings of 60 and 30 minutes respectively. If a sprinkler system is installed in the building the firecell ratings may be reduced by 50%.

If each floor of the building is considered a firecell only the exitways and floor/ceiling assemblies will have to be fire rated.

The costs of various fire rated elements are shown in Table 9[xxv], these figures have been compiled by independent quantity surveyors and includes the costs of all labour, materials, plant and handling.

Rating (mins)	Material	Cost ($/m$^{2)}$
15	9.5 Standard Gib	82.25
30	12.5 Standard Gib	89.17
60	12.5 Fyreline	90.41

Table 9; Costs of Passive Floor/Ceiling Systems

F and S ratings

The buildings F rating requirements may be lowered from 60 to 30 minutes this would means a reduction in cost per metre squared of firecell rated wall of (90.41-89.17) or \$1.24/m^2. Every floor/ceiling assembly in this structure must be fire rated giving a total area of (400 x 6) or 2400 m^2. 15% will be added to this figure to include items such as firestopping of holes for services, fire rated doors, and other F ratings required by the approved documents giving a total area of 2760 m^2.

Therefore the benefit provided by reduced F rating requirements is (2760 x 1.24) or \$3422.

It can be safely assumed a building of this type must have an S rating as they are most often found on the outskirts of CBD's in densely packed groups. Table A1 of the fire safety annex of the approved documents indicates both of these purpose groups are fire hazard category 2.

If we assume an A_V/A_f ratio of 0.05 and an A_h/A_f ratio of Table 1 in section C3 of the approved documents gives a t_e of 130 minutes. If sprinklers are installed this figure may be reduced by 50%.

Passive protection for the structure is difficult to estimate due to the method of quoting coverings per metre sqaured. Consultation with quantity surveyors has indicated an approximate figure for the passive protection required for this building would be \$100 000. If the required rating was halved to 65 minutes the protection wouold cost approximatly \$60 000, giving a net benefit of \$40 000.

Fatalities and Injuries

Fire service incident reports[xxvi] show an average of 159 fires in buildings of this type over the period 1986-1992 In these fires there was 1 fatality in a sprinklered building. Therefore over the period of the study we will predict 5 deaths in buildings of this type where sprinklers are not present.

Over the same period 32 injuries in unsprinklered buildings and 2 injuries in sprinklered buildings were reported. Therefore predictions for injury in a sprinklered and unsprinklered office buildings are 10 and 160 respectively.

If we assume there are 550 buildings of this type in the country[xxvii] (and there will be for the next 30 years) will can calculate the figures in Table 10

	Probability of death	Cost of death	Probability of injury	Cost of injury
Sprinklered	0	0	0.0036	144
Unsprinklered	0.0091	7280	0.0582	2328

Table 10; Costs of fatalities and injuries in office buildings

Therefore the benefits of utilising the trade off clauses for buildings of this type are (7280-0) or 7280 for fatalities and (2328-144) or 2184 for injuries.

Insurance

A building of this type would be worth approximately 20 million dollars and insurance rates for office blocks are in the order of \$0.015 - 0.02 per \$100 cover[xxviii]. Therefore, the insurance premium for the building will be \$4000 at most. The reductions in premiums given by insurance companies vary greatly from company to company and would also be judged on other factors such as the buildings fire history. Generally a 20% discount is given to a building with no peculiarities. Thus the expected saving in this case is estimated as $800 per year. Taking this cost over 30 years gives a uniform present worth of $11 000

Property

If we consider there are 550 buildings of this type in the country and we predict (159 x 30) or 4 770 fires over the course of this study the probability of a fire occurring in any structure of this type is 8.67, that is this event would be expected to occur over 8 times in each building during the study period.. It is known from the risk analysis already completed that 60% of fires in sprinkled buildings are too small to operate the sprinklers (based on fire service statistics), therefore in 5.2 of these 8.67 fires the fire would be expected to be confined to the object of origin and the damage would be minimal. This leaves us with 3.45 major events.

It is estimated that the total loss of fires in this type of building over the next 30 years will be between 600-650 million dollars which would average to $136 300 per incident. Thus the total saving for this analysis is (3.45 x 136 300) $470 235.

If sprinklers are present the damage to the structure would be expected to be minor in 99.97% of cases which would place the probability of a major event occurring in this structure at 0.0010 which corresponds to a dollar value of $136. When sprinklers activate property losses per event will be reduced to $20,000 giving an expected loss over the study of (3.45 x 20 000) or $69 000.

These figures indicate a net benefit where sprinklers are installed of (470 235 - 69 136) or $401 099.

	Benefit ($)
Reduced F ratings	3 422
Reduced S ratings	40 000
Savings of life	7 280
Savings of injury	2 184
Savings of property	401 235
Savings in insurance	11 000
total	465 121

Table 11; Benefits of utilising trade offs

Therefore the outcome for this case is shown in Table 12

	Office Building
Benefits	465 121
Costs	317 350
Benefits-Costs	147 771

Table 12; Results of analysis on office building

14.5. Case 2: Warehouse Building

The warehouse chosen for this analysis is typical of distribution or storage warehouses seen throughout the country at transport centres such as airports or rail yards. The structure has been taken as 60 metres long and 30 metres wide with a ceiling of 8 metres.

14.5.1. Costs

A sprinkler system for a building such as this would be much cheaper than the previous example due to the reduced covered area and the open plan design of the structure. The cost was taken as $86 500[xxii] with an annual inspection fee of $2000 for inspection and maintenance yielding a UPW of $27 530.

	Cost ($)
Sprinkler Installation	86 500
Sprinkler Maintenance	27 530
total	114 030

Table 13; Costs of utilising trade offs

14.5.2. Benefits

F and S Ratings

A building such as this requires limitation of the firecell area to 1500 m^2. To limit the size a partition is required across the shortest width of the structure. The area of the partition will be required to be 240 m^2 and would be expected to cost (82.25 x 240) or $3 290. If the building contains sprinklers this division is not required producing a benefit for this example of $3 240.

This building will also require an S rating as they are often on small properties and near boundaries. Table A1 of the fire safety annex of the approved documents indicates this building would have a fire hazard category 3.

It can be assumed this building will have an A_V/A_f ratio of 0.12 (considering a large open door at each end) and an A_h/A_f ratio of 0 Table 1 in section C3 of the approved documents gives a t_e of 116 minutes. If sprinklers are installed this figure may be reduced by 50%.

Once again the figures for passive protection on structural elements has been approximated due to the detailed information reuired for accurate pricing. To protecte a building of this type with a 116 minute rating would be expected to cost $40 000, if the requirement was lowered to 58 minutes the approximate cost would be $30 000. Therefore, the net benefit due to lowered structural protection is $10 000.

Fatalities and Injuries

Fire Service incident reports show an average of 116 fires in buildings of this type over the period 1986-1992 in these fires there were no fatalities.

Over the same period 6 injuries in unsprinklered buildings and 1 injury in sprinklered buildings were reported. Therefore it could be expected the number of injuries in sprinklered and unsprinklered buildings of this type to be 30 and 5 respectively over the period of the study.

There are 700 buildings of this type in the country[xxvii] (and it can be assumed there will be for the next 30 years) this gives the figures in Table 14.

	Probability of death	Cost of death	Probability of injury	Cost of injury
Sprinklered	0	0	0.0071	286
Unsprinklered	0	0	0.0429	1716

Table 14; Costs of fatalities and injuries in office buildings

Therefore there is no benefit from improved life safety in this building, injury costs reduce from 1716 to 286 yielding a benefit of $1430.

Insurance

A building of this type would be worth approximately 1 million dollars and insurance rates for warehouses are in the order of $0.02 - 0.023 per $100 cover[xxviii]. Therefore, the insurance premium for the building will be $230 at most. Using the same 20% reduction rate on premiums the building owner will save $46. Taking this cost over 30 years gives a uniform present worth of $633

Property

If we consider there are 700 buildings of this type in the country and we predict (116 x 30) or 3 480 fires over the course of this study the probability of a fire occurring in any structure of this type is 4.917. . Once again 60% of these fires are discounted as minor leaving 1.97 major incidents per building in the 30 year period.

It is estimated that the total loss of fires in this type of building over the next 30 years will be between 1400-1500 million dollars which would average to 402 298 dollars per incident

Expected losses due to fires in buildings of this type over the next 30 years is expected to be 1400 1500 million which would average $431 034 per incident. Thus the total losses in unsprinklered buildings is (1.97 x 431 034) or $849 137.

If sprinklers are present the damage to the structure would be expected to be minor in 99.97% of cases which would place the probability of a major event occurring in this structure at 0.0591 which corresponds to a dollar value of 25 470 dollars. When sprinklers activate property losses per event will be reduced to 38 000 dollars giving an expected loss over the study of (1.97 x 38 000) or $74 860.

These figures indicate a net benefit where sprinklers are installed of (849 137 - 74 860) or $774 277.

		Benefit ($)
Reduced F ratings		3240
Reduced S ratings		10 000
Savings of life		0
Savings of injury		1430
Savings of property		774 277
Savings in insurance		633
	total	789 580

Table 15; Benefits of utilising trade offs

Thus the results of the cost benefit analysis for a warehouse building are shown in Table 16

	Warehouse	
Benefits		789 580
Costs		114 030
	Benefits-Costs	675 550

Table 16; Benefits - Costs for warehouse analysis

14.6. Conclusions

The cost benefit analysis has shown that although the savings from reduced passive protection are minor compared to the costs involved in installing a sprinkler system, other benefits make it an attractive economical proposition.

Although the savings through utilising the trade offs are not large the lives that are predicted to be saved could be valued much higher than the accepted figures used increasing the attractiveness of the trade off case.

Another point of interest is the low fatality rate in the two property types examined. If a rest home or institution were to be examined the savings from reduced number of expected fatalities would be much higher.

15. Conclusions and Recommendations

The general conclusion from this study is that sprinkler trade offs are a valuable tool in fire protection in this country. If for no other reason than they encourage building owners to install sprinklers. The installation of sprinklers will increase the overall life safety of the building, provided the trade offs are not excessive.

A method for determining the correct level of trade off is difficult to establish due to the fact that active and passive systems are two distinct types of protection with two different methods and goals. It is considered illogical, however, to totally remove some measure of passive protection because there is always a possibility of a sprinkler failure.

The level of trade offs in passive systems allowed by the Approved Documents appears to provide a bare minimum of life safety in the event of a sprinkler failure.

If we are to rely on passive systems in buildings when sprinklers fail, efforts must be made to ensure the passive systems do not fail as well.

Although the trade offs allowed in the Approved Documents are acceptable for life safety, they may result in increased property losses in some cases. In specific situations where property protection may be lowered by the removal of some passive systems, it may be prudent for the building owner to not use all of the permitted trade offs, especially if the contents of the building are valuable or considered vital to business.

Another important point is the fact sprinkler trade offs can only be considered safe if the sprinkler reliability rate in this country remains at a level seen in the past. If significant changes were to be made to the way sprinklers are installed, maintained and controlled the problem would have to be reconsidered.

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Appendicies

New Zealand Building Code Section C2/AS1

2.5.2 Sprinklers

Where the firecell is protected by a sprinkler system (fire safety precaution type 6), open path lengths given in Table 3 may be increased by 50%

New Zealand Building Code Section C3/AS1

2.0 FIRECELLS

2.4 **Protected Shafts**

2.4.2 Every protected shaft shall be a seperate firecell within the firecell or firecells in which it is located. The shaft walls between each floor shall have a FRR of no less than the highest F rating of any firecell abutting at that level, or 30/30/30, whichever is greater. The FRR shall be applied to the external face of the fire seperation surrounding the protected shaft.

2.4.3 In sprinklered buildings the F rating of the protected shaft may be reduced by 30 minutes, but shall be no less than 30/30/30

2.5 **Purpose Groups CS and CL**

2.5.2 If CS or CL spaces are sprinklered the FRR requirements of 2.5.1 may be reduced as follows

a) Firecells having fire separations with a FRR of 15/15/15 may be replaced with smokecells (and)
b) Provided the occupant load in the firecell is not greater than 1000, the FRR of fire separations may be reduced from 30/30/30 to 15/15/15

2.5.3 Theatres — Amd 3. Dec '95

.... Where the stage and supporting areas are sprinklered as required by Paragraph 9.9.1, the proscenium wall and curtain may be a smoke separation. The openings in fire rated proscenium walls shall be protected as required by Paragraph 5.4

2.7 **Purpose group CO**

2.7.1 Any enclosed usable space beneath tiered seating shall be a firecell with a rating of no less the F30. This provision need not apply if the lower space is sprinklered

2.8 **Purpose groups SC and SD**

2.8.10 Provisions and requirements for sprinklers — Amd 3. Dec'95

a) Where the sleeping area is sprinklered
   i) the maximum number of beds permitted by Paragraphs 2.8.2 2.8.3 and 2.8.5 may be doubled if the sleeping area is a single firecell, and — Amd 3. Dec '95
   ii) The FRR of 60/60/60 required by Paragraph 2.8.2 may be reduced by 30/30/30, and the FRR 30/30/30 required by Paragraph 2.8.5 reduced to 15/15/15 — Amd 1. Dec '93

2.9 Purpose group SA

2.9.7 Provision and Requirements for sprinklers

Where an SA purpose group sleeping area is sprinklered

a) The number of beds allowed under Paragraph 2.9.2 may be doubled
b) Provided the number of beds in each firecell is no greater than 60, the FRR of fire separations between adjacent sleeping areas may be reduced from 30/30/30 to 15/15/15

2.11 **Purpose group IE**

2.11.5 Provision for sprinklers

Where firecells adjacent to the safe path are sprinklered, the FRR's required by Paragraph 2.11.2 may be reduced to 15/15/15 and 30/30/30 respectively, but to not less than the F rating for each purpose group as determined from Table B1

2.12 **Purpose group IA**

2.12.5 FRR's for building elements in car parking spaces shall be based on the S rating as derived from the formula:

$S = Ct_e$ (but in no case less than 15 minutes)

Where t_e (equivalent time of fire exposure in minutes) is derived from Table 1, and C is a variable having the following values:

For fire separations between firecells:

C = 1.0 if unsprinklered, or
= 0.5 if sprinklered

Amd 1. Dec '93

For floors and supporting elements within the car parking firecell:

C = 0.5 if unsprinklered
= 0.25 if sprinklered

Amd 1. Dec '93

2.14 **Cross lease titles, company lease titles and unit titles**

2.14.2 When a building is subdivided (as in Paragraph 2.14.1) and all the titles and any areas in common are sprinklered throughout, the requirements for fire separations of Paragraph 2.14.1 b) need not apply

Amd 1. Dec '93

2.16 **Wood and wood products**

2.16.1 Floors

In any firecell which has another firecell below, and where the required F or S rating is:

a) 60 minutes or more, the flooring within that firecell shall, if constructed of wood products, be covered by a non-combustible overlay, unless the firecell is sprinklered
b) 30 minutes or less, the flooring may be of wood products, provided it has a thickness of no less than 20mm

2.16.2 Walls and ceilings

In any firecell, when the required F or S rating is:

a) 60 minutes or more, and the internal walls and ceilings are lined with wood or wood products thicker than 1.0mm, unless the firecell is sprinklered the S rating shall be increased by applying the requirements of the next higher fire hazard category of Table 1

2.17 **Fire service vehicular access**

2.17.1 Where buildings are located remote from the street boundaries of a property, pavements situated on the property and likely to be used for vehicular access by fire appliances shall:

e) Provide access to within 18m of at least one side of the building, except that when a building is sprinklered and has a fire riser main installed, access need only be to within 18m of the inlets to these systems

3.0 FIRE RESISTANCE RATINGS

3.7 **Special requirements**

3.7.3 When a firecell is sprinklered, except when purpose groups require subdivision or other area limitations are imposed by this Approved Document, the firecell floor area may be unlimited

4.0 EXTERNAL WALLS AND ROOFS Amd 1. Dec '93

4.4 **Vertical flame spread**

4.4.5 Except when the firecells are sprinklered, one of the measures described in Paragraphs 4.4.6 to 4.4.7 shall be provided where either of the following conditions occur:

a) Firecells containing purpose groups SC, SD, SA, SR or IE are one or more levels above the final exit, or
b) Firecells containing purpose group CM are two or more levels above the final exit.

4.8 **Roofs** Amd 2. Aug '94

4.8.3 When an external exitway crosses a roof, or is above or adjacent to a roof on the same or another building, unless the firecell below the roof is sprinklered, the roof within 3.0m of any part of the exitway, and all supporting elements, shall have a FRR of 30/30/30. Primary elements of the exitway shall be non combustible.

5.0 CLOSURES IN FIRE AND SMOKE SEPARATIONS

5.5 **Protected shafts**

5.5.3 For purpose groups other than SC and SD, the smokecell may be omitted where the firecell is sprinklered and has an automatic smoke detection system.

8.0 SURFACE FINISHES, FLOOR COVERINGS AND SUSPENDED FLEXIBLE FABRICS

8.1 **General Principles**

8.1.5 Sprinklered spaces

In firecells equipped with sprinklers, only the ceilings need comply with the SFI and SDI requirements of Table 4

8.2.3 In firecells equipped with sprinklers the flooring need not comply with the requirements in Paragraph 8.2.1

Uniform Building Code, USA

Sec 506 Allowable area Increases

3. (c) Automatic Sprinkler Systems

The areas specified in Table No. 5-c and section 505 (b) may be tripled in 1 storey buildings and doubled in buildings of more than one storey if the building is provided with an automatic sprinkler system throughout. The area increases permitted in this subsection may be compounded with that specified in section 1, 2, or 3 of subsection (a) of this section. The increases permitted in this subsection will not apply when automatic sprinkler systems are installed under the following provisions.

1. Section 507 for an increase in allowable number of stories.
2. Section 3802 (f) for group H, Divisions 1, 2, and 3 occupancies
3. Substitution for a 1 hour fire resistive construction pursuant to Section 508
4. Section 1716, Atria.

Sec 508 Fire Resistive Substitution

When an approved automatic sprinkler system is not required throughout a building by other sections of this code, it may be used in a building of type II one hour construction, Type III one hour and type V one hour construction to substitute for the one hour fire resistant construction. Such substitution shall not waive or reduce the required fire resistive construction for:

(a) Occupancy separations [section 503 (c)]
(b) Exterior wall protection due to proximity of property lines [Section 504 (b)]
(c) Area separations [Section 505 (f)]
(d) Dwelling Unit separations [Section 1202 (b)]
(e) Shaft enclosures [Section 1706]
(f) Corridors [Section 3305 (g) and (h)]
(g) Stair enclosures [Section 3309]
(h) Exit passageways [Section 3312 (a)]
(i) Boiler, Central heating plant or hot water supply boiler room enclosures.

Sec 509 Pedestrian Walkways

(c) Maximum Length. The length of a pedestrian walkway shall not exceed 300 feet

EXCEPTIONS 1. Pedestrian walkways that are fully sprinklered may be up to 400 feet in length

Sec 702 Construction, Height and Allowable Area

(b) Special Provisions. 1. Group B division 1 with Group A division 3; Group B division 2 or Group R, division 1 occupancy above. Other provisions of this code notwithstanding, a basement or first story of a building may be considered as a separate and distinct building for the purposes of area limitations, limitation of number of stories and type of construction, when all of the following conditions are met

A. The basement or first storey is of Type I construction and is separated from the building above with a three hour occupancy separation
B. The building above the three hour occupancy separation contains only Group A division 3, Group B division 2, or Group R division 1 occupancies
C. the building below the three hour occupancy separation is used exclusively for the parking or storage of private or pleasure type vehicles

EXCEPTIONS 2. Group B division 2 office and retail occupancies in additional to those incident to the operation of the building (including storage areas) provided that the entire structure below the three hour occupancy separation is protected throughout by an automatic sprinkler system.

2. Group B division 2 Storage Areas. Storage areas in connection with wholesale or retail sales in Division 2 occupancies shall be separated from the public areas by a 1 hour fire resistive occupancy separation.

EXCEPTIONS: Occupancy separation need not be provided when any one of the following conditions exists

A. The storage area does not exceed 1000 square feet, or
B. The storage area is sprinklered and does not exceed 3000 square feet , or
C. The building is provided with an automatic sprinkler system throughout. Area increases as specified in section 506 (c) are permitted.

Sec 706 Shaft and Exit Enclosures

Exits shall be enclosed as specified in Chapter 33

Elevator shafts, vent shafts and other openings through floors shall be enclosed, and the enclosures shall be specified in section 1706

EXCEPTIONS: In Group B division 4 occupancies, exits shall be enclosed as specified in chapter 33, but other through floor openings need not be enclosed.

In buildings housing group B occupancies equipped with automatic sprinkler systems throughout, enclosures need not be provided for escalators where the top of the escalator opening at each story is provided with a draft curtain and automatic sprinklers are installed around the perimeter of the opening within 2 feet of the draft curtain. The draft curtain shall enclose the perimeter of the unenclosed opening and extend from the ceiling downwards at least 12 inches on all sides. The spacing between sprinklers may not exceed 6 feet.

Sec 802 Construction Height and Allowable Area

(c) Special Provisions. Rooms in division 1 and 2 occupancies used for kindergarten, first or second grade pupils and division 3 occupancies shall not be located above or below the first storey, except for basements that have required exits at grade level.

EXCEPTIONS: 1. In buildings equipped with automatic sprinkler systems throughout, rooms used in kindergartens, first and second grade children or for day care purposes may be located on the second storey, provided there are at least two exits directly to the exterior for the exclusive use of the occupants, or

2. In buildings equipped with an automatic sprinkler system throughout and of Type I or Type 2 fire resistive construction, day care facilities are permitted to be located above the first floor when

A. The entire storey on which the day care facility is located is equipped with an approved fire alarm and smoke detection system as set forth in the fire code. Actuation of the system shall sound an audible alarm through the day care facility; and

B. The day care facility is divided into two areas with a 20 minute fire resistive separation.

C. Each area is provided with air moving equipment

D. Each area has no fewer than two exits

Sec. 1002 Construction Height and Allowable Area

(a) General. Buildings or parts of buildings classed in Group I because of the use or character of the occupancy shall be limited to the types of construction set forth in tables nos. 5-C and no. 5-D and shall not exceed in area or height, the limits specified in sections 505, 506 and 507

EXCEPTIONS: 1. Hospital and nursing homes specified as Group I division 1.1 occupancies that are equipped with an automatic sprinkler system throughout shall not exceed 1 storey in height when in Type III 1 hour, Type IV or Type V 1 hour construction

Sec 1211. Fire Alarm Systems

Group R division 1 occupancies shall be provided with an approved manual and automatic fire alarm system in apartment houses 3 or more stories in height or containing 16 or more dwelling units, in hotels 3 or more stories in height or containing 20 or more guest rooms and in congregate residences three or more stories in height and having an occupancy of 20 or more. A fire alarm and communicating system shall be provided in Group R division 1 occupancies located in a high rise building.

EXCEPTIONS: 2. A manual fire alarm need not be provided in a building which is protected throughout by an approved supervised fire sprinkler system having a local alarm to notify all occupants.

Sec. 1704 Vertical Fire Spread at Exterior Walls

(c) Exterior. When openings in an exterior wall are above and within 5 feet laterally of an opening in the storey below, such openings shall be separated by an approved flame barrier extending 30 inches beyond the exterior wall in the plane of the floor or by an approved vertical flame barrier not less than 3 feet high measured vertically above the top of the lower opening. Flame barriers shall have a fire resistance of not less than ¾ of an hour.

EXCEPTIONS: 1. Flame barriers are not required in a building equipped with an approved automatic sprinkler system throughout.

Sec 1713 Foam Plastic Insulation

(d) Thermal Barrier. The interior of the building shall be separated from the foam plastic insulation by an approved thermal barrier having an index of 15 when tested in accordance with UBC Standard no. 17-3. The thermal barrier shall be installed in such a manner that it will remain in place for the time of its index classification based on approved diversified tests.

EXCEPTIONS: The thermal barrier is not required:
E. In cooler and freezer walls when
(iv) Is protected by an automatic sprinkler system. When the cooler or freezer is within a building, both the cooler or freezer and that part of the building in which it is located shall be sprinklered.

Sec. 1716 Atria

(c) Enclosure of Atria
Fixed glazed openings in the atrium enclosure shall be equipped with fire windows having fire resistive rating of not less than ¾ hour, and the total area of such openings shall not exceed 25% of the area of the common wall between the atria and the room into which the opening is provided.

EXCEPTIONS: 2. Guest rooms, dwelling units, congregate residences and tenant spaces may be separated from the atrium by approved fixed wire glass set in steel frames. In lieu thereof, temeed or laminated glass or listed glass block may be used, subject to the following

A. The glass shall be protected by a sprinkler system equipped with listed quick response sprinklers. The sprinkler system shall completely wet the entire surface of the glass wall when actuated. Where there are walking surfaces on both sides of the glass both sides of the glass shall be so protected.

Sec 1807 Special Provisions for Group B division 2 Office Buildings and Group

R division 1 Occupancies

(c) Automatic Sprinkler Systems

2. Modifications. The following modifications of the code requirements are permitted.
   - A. The fire resistive time periods set out in table 17-A may be reduced one hour for interior bearing walls, exterior bearing and non bearing walls, roofs and beams supporting roofs, provided they do not frame in to columns. Vertical shafts other than stairway enclosures and elevator shafts may be reduced to one hour when sprinklers are installed within the shafts at alternate floors. The fire resistive time period reduction as specified herein shall not apply to exterior bearing and non bearing walls whose fire resistive rating has already been reduced under the exceptions contained within Section 1803 (a) or 1903 (a)
   - B. Except for corridors in Group B, division 2 and Group R, division 1 occupancies and partitions separating dwelling units or guest rooms, all interior non bearing partitions required to be 1 hour fire resistive construction by Table no. 17-A may be of non combustible construction without a fire resistive time period.
   - C. Travel distance to the most remote point in the floor area to a horizontal exit or to an enclosed stairway may be 300 feet.
   - D. Fire dampers, other than those needed to protect floor ceiling assemblies to maintain the fire resistance of the assembly, are not required.
   - E. Emergency windows required by section 1204 are not required.

(h) Elevators. 1. Elevators on all floors shall open in to elevator lobbies which are separated from the remainder of the building, including corridors and other exits, by walls extending from the floor to the underside of the fire resistive floor or roof above. Such walls shall not be of less than 1 hour fire resistive construction. Openings through such walls shall conform to section 3305

EXCEPTIONS: 3. In fully sprinklered office buildings, corridors may lead through enclosed elevator lobbies if all areas of the building have access to at least one required exit without passing through the elevator lobby.

Sec 2516 General Construction Requirements

(f) Fire Blocks and Draft Stops

(ii) Two or More Dwelling Units and Hotels. Draft stops shall be installed in the attics, mansards, overhangs, false fronts set out from walls and similar concealed spaces of buildings containing more than one dwelling unit and in hotels. Such draft stops shall be above and in line with walls separating individual dwelling units and guest rooms from each other and from other uses.

EXCEPTIONS: 2. Where approved sprinklers are installed, the area between draft stops may be 9000 square feet and the greatest horizontal dimension may be 100 feet.

Sec. 5207 Skylights

(a) General

4. Each skylight unit may have may have a maximum area within the curb of 100 square feet for CC2 material and 200 square feet for CC1 material

EXCEPTIONS: 2. Except for Groups A, divisions 1 and 2 and H, divisions 1 and 2 occupancies the maximum area within the curb need not be limited where skylights are.

B. Used in a building completely equipped with an approved automatic sprinkler system complying with UBC Standard no. 38-1 or 38-3

Building Code of Australia (Section C - Fire Resistance)

C2.3 Large Isolated Buildings

The size of a fire compartment in a building may exceed that specified in Table C2.2 where -

(a) the building does not exceed 18 000 m^2 in floor area nor exceed 108 000 m^3in volume if -

(ii) the building is of any class and is protected throughout with a sprinkler system and perimeter vehicular access complying with C2.4(b) is provided ; or

(b) the building exceeds 18 000 m^2 in floor area or 108 000 m^3 in volume, is protected throughout with a sprinkler system, is provided with a perimeter vehicular access complying with 2.4(b) and if -

(i) the ceiling height of the fire compartment is not more than 12m, it has a smoke exhaust system in accordance with Specification E2.6 or smoke and heat vents in accordance with E2.5; or
(ii) the ceiling height is more than 12m, it has a smoke exhaust system in accordance with specification E2.6; or

(c) there is more than one building on the allotment -

(i) each building must comply with (a) or (b); or
(ii) if the buildings are closer than 6m to each other they are regarded as one building and collectively must comply with (a) or (b).

C2.6 Vertical Separation of Openings in External Walls

If a building (other than an open deck carpark or an open spectator stand) which is required to be of Type A construction and does not have a sprinkler system, any part of a window or other opening in an external wall (except openings within the same stairwell)-

(i) is above another opening in the storey next below; and
(ii) its vertical projection falls no farther than 450mm outside the lower opening (measured horizontally),

the openings must be separated by -

(a) a spandrel which -

(i) is not less than 900mm in height; and
(ii) extends not less than 600mm above the upper surface of the intervening floor; and
(iii) is of non-combustible material having a FRL not less than 60/60/60; or

(b) part of a curtain wall or panel wall that complies with (a); or

(c) construction that complies with (a) behind a curtain wall or panel wall and has any gaps packed with non combustible material that will withstand thermal expansion and structural movement of the wall without loss of seal against fire and smoke; or

(d) a slab or other horizontal construction that -
(i) projects outwards from the external face of the wall not less than 1100mm; and
(ii) extends along the wall no less than 450mm beyond the openings concerned; and
(iii) is non-combustible and has a FRL of not less than 60/60/60; or

(e) other construction which is equally as effective as (a), (b), (c), or (d)

C2.7 Separation by Fire Walls

A part of a building separated from the remainder of the building by a fire wall is treated as a separate building if -

(d) where the roof of one of the adjoining parts is lower than the roof of the other part, the fire wall extends to the underside of-

(iii) the lower roof if its covering is non combustible and the lower part has a sprinkler system,

or the design of the building must otherwise restrict the spread of fire from the lower part to the higher part.

C2.10 Separation of Lift Shafts

Lifts connecting more than 2 storeys, or more than 3 storeys if the building is sprinklered, (other than lifts which are wholly within an atrium) must be separated from the remainder of the building by enclosure in a shaft which -

(a) in a building required to be of Type A construction - the walls have the relevant FRL prescribed by Specification C1.1;
(b) in a building required to be of Type B construction the walls are -
  (i) in accordance with (a) if the shaft is loadbearing; or
  (ii) of non-combustible construction if the shaft is non loadbearing ; and
(c) openings for lift landing doors and services are protected in accordance with Part C3

C3.4 Acceptable Methods for Protection

(a) Where protection is required , doorways and windows and other openings must be protected as follows;
  (i) Doorways - external wall wetting sprinklers or 60/60/60 fire doors (self closing or automatic closing)
  (ii) Windows - external wall wetting sprinklers 60/60/- fire windows (automatic or permanently fixed in the closed position) or 60/60/- automatic fire shutters
  (iii) Other openings - external wall wetting sprinklers or construction not having an FRL not less than 60/60/-

Building Code of Australia (Section D Access and Egress)

D1.3 When Fire Isolated Exits are Required

(b) Class 5 to 9 Buildings - Every exit must be fire isolated unless

(i) It doesw not connect more than 2 consecutive storeys

(ii) It is part of an open spectator stand

(iii) It does not connect more than 3 consecutive storeys if the building has a sprinkler system installed throughout.

C 1.12 Non Required Stairways Ramps or Escalators

(b) may connect any number of storeys if it is:-

(iii) In a class 5 or 6 building that is sprinklered throughout

(c) except where permitted in (b) must not connect more than

(i) 3 storeys if each of those storeys is provided with a sprinkler system throughout.

NZS 1900 Chapter 5 (1988)

AMENDMENTS INCORPORATED IN THE 1984 EDITION

No.	Date of Issue	Description	Notes
12	24/7/78	Additional "credits" for automatic sprinkler systems.....	
1	22/10/87	...editorial changes in relation to references to automatic sprinkler systems within the text.	Incorporated in this edition

FORWARD TO THE 1984 EDITION, INCORPORATING AMENDMENT No. 16

1. Major changes were introduced by Amendment No. 12 (1978), especially with the insertion of table 1A, which permitted lowering of "types of construction" required where sprinkler protection is provided, thus enabling more extensive use of timber structural elements....

5.10.4
When a fire compartment is protected by an approved automatic sprinkler system then;

Either

(a) The maximum area permitted by clause 5.9 shall be doubled when the sprinkler system is single supply and shall be unlimited when the sprinkler system is double supply

or

(b) Table 1A may be used instead of table 1, whether the sprinkler system is double or single supply, provided this shall not apply to cases where a sprinkler system is required by 5.52 (certain shops), 5.89.1 (D2 and D3 buildings exceeding 24.4m in height) or 5.90.1 (any building exceeding 45.7m in height).

Provided that no account shall be taken of any sprinkler system if, in the opinion of the Engineer, the contents of the fire compartment are such that the application of water would be ineffective or may be dangerous.

5.12.6
where approved
i. Thermally operated sealed drenchers
ii. Automatically controlled open drenchers
iii. Manually operated drenchers are installed and maintained in an approved manner to deliver water upon the outer surface of external walls including openings there in the percentage of window openings may be doubled

5.14.3
Subclause 5.14.1 (fire resistance of external walls) shall not apply when all the members on which the wall depends for its stability are in a fire compartment or part of a fire compartment protected by an approved automatic sprinkler system.

TABLE 3
INTERNAL F.R.R. FOR TYPES 1, 2, AND 3 CONSTRUCTION

MINIMUM FIRE RESISTANCE RATINGS IN HOURS FOR ELEMENTS OF STRUCTURE OTHER THAN EXTERNAL AND FIRE WALLS AND FIRE PARTITIONS

Applies to types 1,2, and 3 construction only; for types 4 and 5 construction refer to clause 5.21.3 and footnotes to tables 1 and 1A (c)

Occupancy classification group clause 5.6	Fire Risk division	Concrete floors, columns, bearing walls, and main beams supporting concrete floors	Columns, bearing wall, and main beams supporting roof members
A Assembly purposes	Low	1(a)	1(b)
Accommodation			
dwellings for	Low	1(a)	1(b)
B.1. Persons under	Low	1(a)	1(b)
restraint	Low	1(a)	1(b)
B.2. Persons needing attention			
B.3. Normal persons			
C.1. Multi-unit dwellings	Low	1(a)	½
C.2. Double and single unit dwellings	Low	1(a)	½
Commercial and			
Industrial	Low	1(a)	1(b)
D.1.	Moderate	1½ (a)	1(b)
D.2.	High	2½ (a)	1(b)
D.3.			
Column 1	2	3	4

NOTE-
(a) Where the fire compartment exceeds four storeys the F.R.R. in column 3 shall be increased by ½ hr. See clauses 5.16.1 and 5.17.1
(b) ½ hr. F.R.R. when the fire compartment is protected by an approved automatic sprinkler system
(c) Clauses 5.12.1(b), 5.16, 5.17, 5.21 and 5.22 should be read in conjunction with this table

5.20.2
Where approved automatic sprinkler protection is provided in adjacent fire compartments the area of the fire door openings between such fire compartments may be increased to not more than $8.4m^2$ (from $5.4m^2$)

5.21.1

On any floor of a fire compartment not coming within occupancy group C1 or C2, all fully enclosed tenancies, according to the fire risk classification of their occupancy as set out in clause 5.6, shall be separated by fire partitions having a F.R.R. of:

(i) ½ hour for a low risk occupancy other than a place of assembly
(ii) 1 hour for a moderate fire risk occupancy or a place of assembly
(iii) 1 ½ hours for a high risk occupancy

Partially enclosed or unenclosed tenancies are acceptable, provided egress routes are not affected:

Provided that any separate tenancy with an independent entrance from a street or public place which exceeds 25% of the maximum area permitted under table 1 for a particular fire compartment shall be separated from other tenancies by fire partitions of double the F.R.R. provided for in items (I) and (ii) of this Subclause, which ever is applicable

Provided also that the above provisions shall not apply to shops or show windows facing on to an arcade or shopping mall, if the entire area of that floor of the fire compartment is protected by an approved automatic sprinkler system.

5.23.6

Pipes or ducts shall be permitted to pass through fire walls, fire partitions, or fire rated floors as follows:

(a) Pipes or ducts not exceeding 2 500 m^2 in cross sectional area - no additional protection required.
(b) Pipes or ducts exceeding 2 500 mm2 but not exceeding 32 000 mm^2 in cross sectional area shall be made of or encased in a material having a melting point in excess of 1000°C for a distance of at least six times the diameter or major dimension of the pipe or duct, on each side of the fire resisting barrier:

Provided that such encasement shall not be required in buildings equipped with an approved automatic sprinkler system, or in areas which in the opinion of the engineer transmission of fire is unlikely or on the outside of any exterior wall or roof.

5.24.4

The requirements for fire partitions in any roof space as specified in 5.24.1, 5.24.2, and 5.24.3 shall not apply to the roof space of any fire compartment protected by an automatic sprinkler system.

5.27.2
In all buildings that are not classified in clause 5.6 under groups B.1, B.2 and B.3, and that are not protected by an approved sprinkler system, all doors opening from a habitable room to a hallway or passageway forming part of the route of travel to an exitway shall be close fitting doors without ventilation, and all lights contiguous to the partition separating habitable rooms from such corridors or passageways shall be fixed sashes glazed with 6 mm Georgian wired glass, or copper light glazing:
Provided that the engineer may waive this requirement in special cases, such as prisons and other special purpose buildings, where he is satisfied that equivalent safety against smoke-logging of hallways and passageways is provided by such factors as continuos supervision and limitations on combustible contents.

5.33.1
One single unit exitway may discharge into the main exitway where there is a smoke stop door at the junction and where between the point of the junction and the point of exit to the street there is not more than one doorway on each side of the exitway;
Provided that each such doorway gives access to the area beyond only through a smoke-stop lobby or, in the case where the area beyond is protected by an approved sprinkler installation, by smoke-stop doors.

5.55.1
The owner of any existing building which does not comply with any or all of the relevant requirements of this bylaw for;

(i) The separation of tenancies by fire partitions as set out in clause 5.21;
(ii) Fire partitions enclosing vertical openings as set out in clause 5.22;
(iii) Surface finish of walls and ceilings (early fire hazard indices or flammability index as appropriate) as set out in clauses 5.25 and 5.52;
(iv) Means of egress as set out in clauses 5.27-5.54 inclusive;

Shall, upon receipt of a written notice from the engineer and within the period stipulated therein, cause the building to cause the building to be bought to that degree of conformity with the requirements of this bylaw as may be stated in such notice, and until he has done so to the satisfaction of the engineer shall comply with any requirements as to the use of the building (including limitations on the numbers of persons to be permitted in the building at any time, limitations on type and amount of goods and chattels to be permitted in the building in the building, and other relevant limitations) that the engineer shall include in such notice.

Provided that no existing building need comply with the requirements as in (I) and (iii) above if it is protected by an automatic fire sprinkler system,

5.82.1

Where a stage floor is raised or the ground under it is excavated to provide a usable space or space in which in the opinion of the engineer could be used for storage or other purposes, such floor shall be of materials and construction providing a 1 hr F.R.R., unless the whole of the area under the stage is protected by an approved automatic sprinkler installation.

5.83.2

All workshops, storerooms, scene docks, property rooms, wardrobe, or painting rooms, in connection with a theatre, shall be separated from the auditorium by the proscenium wall and from the stage area by a 2 hr. F.R.R. wall, and be separated from each other by fire partitions having a 1 hr. F.R.R. except that when an approved automatic sprinkler system installation is installed and the total area of the rooms so separated is not greater than 200 m^2 the F.R.R's may be halved (that is, 1 hr and ½ hr. respectively).

5.85.1

For other than normal rooms the materials and construction surrounding all built in spaces which are provided with access of any nature, for example, under stairways, galleries, and similar areas, shall provide a 2 hr. F.R.R.:

Provided that where such spaces are protected by an approved automatic sprinkler installation with sprinkler heads spaced at approved distances, the F.R.R. shall be not less than ½ hr.

5.88.3

In addition to the requirements of clause 5.25, the following requirements shall be met;

(i) All combustible lining material attached directly to the framing shall be backed by non combustible material provided that this requirement shall not apply to any materials comprising less than 5 % of the total sub divisions of a floor.

(ii) The surface finish of walls and ceilings in main circulation corridors shall be restricted to materials having early fire hazard indices not higher than:

Spread of flame index 2
Smoke developed index 5

Provided that where approved automatic fire sprinkler system is installed, the requirements for control of wall, ceiling and interior finishing materials need not apply.

Table 1
FIRE COMPARTMENTS WITHOUT SPRINKLERS
MAXIMUM ALLOWABLE AREAS, NUMBER OF STOREYS AND MINIMUM TYPE OF CONSTRUCTION REQUIRED IN FIRE COMPARTMENTS FOR VARIOUS OCCUPANCIES WITHOUT SPRINKLER PROTECTION

Note: Clauses 5.3, 5.6, 5.8, 5.9, 5.10 and 5.16 will assist users in the application of this table

Occupancy Classification See clause 5.6			With component parts complying with the fire resistance rating as set out in tables 2 and 3 and clauses 5.11, 5.16, and 5.17 for erection in:								
			Central Fire Risk Areas			Outer A Fire Risk Areas			Outer B Fire Risk Areas		
Fire Risk Group	Fire Compartment for use as	Fire Risk Division	Area m^m	Storeys	Types of Construction	Area	Storeys	Types of Construction	Area	Storeys	Types of Construction
A	Assembly Purposes	Low	3000 2000 1500 1000	1 2 (b) 2(a)	2 2 2 2	2000 800 3000 2000 1500 1000	1 2(a) 1 2 (b) 2(a)	4 4 3 3 3 3	500 250	1 2(a)	5 5
B.1	Accommodation dwellings for: Persons under restraint	Low	800	(b)	2	(see clause 5.9.2.2)			(see clause 5.9.2.2)		
B.2	Persons needing attention	Low	1200 1000	1 (b)	2 2	1000 1200 1000	1 1 2	4 3 3	(see clause 5.9.2.2)		
B.3	Normal Persons	Low	1500 1200 600	1 (b) 2(a)	2 2 2	1200 300 1500 1200 1000 600	1 2(a) 1 2 (b) 2(a)	4 4 3 3 3 3	600 300	1 2(a)	5 5
C.1	Multi Unit Dwellings	Low	1200	(b)	2	1200 800	2 (b)	3 3	(see clause 5.9.2.2)		
C.2	Single and double unit dwellings	Low	As for B.3 (e)			As for B.3 (e)			300 (c) 150 (c)	As for B.3 (e) but: Two (d) Two and ½ (d)	5 5
D.1	Commercial and Industrial buildings	Low	4000 3000 2000 600	1 2 (b) 2(a)	2 2 2 2	3000 400 4000 3000 2000 600	1 2(a) 1 2 (b) 2(a)	4 4 3 3 3 3	800 400	1 2 See subclause 5.9.2.2	5 5
D.2	Ditto	Mod	3000 2000 1500 500	1 2 (b) 2(a)	2 2 2 2	2400 300 3000 2000 1500 500	1 2(a) 1 2 (b) 2(a)	4 4 3 3 3 3	See subclause 5.9.2.2		
D.3	Ditto	High	1500 1000 500	1 2 (b)	1 1 1	2000 1500 1000	1 2 (b)	1 1 1	See subclause 5.9.2.2		
1	2	3	4	5	6	7	8	9	10	11	12

NOTE:-

(a) Timber upper floor of ½ hr. F.R.R. and lined throughout with material to provide a construction having a ½ hr F.R.R. and provided there is no place of assembly, as defined herein, on the upper floor

(b) Number of storeys not limited by this table

(c) Provided the engineer may allow a larger area if he is of the opinion that the separation distance, means of egress, and other considerations warrant.

(d) Single unit dwellings only

(e) But not less than the F.R.R. in clause 5.21.3

Table 1A

FIRE COMPARTMENTS WITH SPRINKLERS

MAXIMUM ALLOWABLE AREAS, NUMBER OF STOREYS AND MINIMUM TYPE OF CONSTRUCTION REQUIRED IN FIRE COMPARTMENTS FOR VARIOUS OCCUPANCIES WITH SPRINKLER PROTECTION, BUT SUBJECT TO 5.10.4(b)

Note: Clauses 5.3, 5.6, 5.8, 5.9, 5.10 and 5.16 will assist users in the application of this table

[illegible]			[illegible]								
			Central Fire Risk Areas			Outer A Fire Risk Areas			Outer B Fire Risk Areas		
Fire Risk Group	Fire Compartment for use as	Fire Risk Division	Area m^m	Storeys	Types of Construction	Area	Storeys	Types of Construction	Area	Storeys	Types of Construction
A	Assembly Purposes	Low	3000	1	3	2000	1	5	See clause 5.9.2.2		
			2500	2	3	800	2(a)	5			
			1500	(b)	3	3000	1	4			
			1000	2(a)	3	2000	2(f)	4			
						1500	4(f)	4			
						1000	2(a)	4			
B.1	Accommodation dwellings for: Persons under restraint	Low	800	(b)	3	See clause 5.9.2.2			See clause 5.9.2.2		
B.2	Persons needing attention	Low	1200	1	3	1000	1	5	See clause 5.9.2.2		
			1000	(b)	3	1200	1	4			
						1000	2(f)	4			
B.3	Normal Persons	Low	1500	1	3	1200	1	5	See clause 5.9.2.2		
			1200	(b)	3	300	2(a)	5			
			600	2(a)	3	1500	1	4			
						1200	2(f)	4			
						1000	4(f)	4			
						600	2(a)	4			
C.1	Multi Unit Dwellings	Low	1200	(b)	3	1200	2(f)	4	See clause 5.9.2.2		
						800	4(f)	4			
C.2	Single and double unit dwellings	Low	As for B.3 (e)			As for B.3 (e)			300 (c)	As for B.3 (e) but; Two (d) Two and a half (d) (e)	5
									150 (c)		5
D.1	Commercial and Industrial buildings	Low	4000	1	3	3000	1	5	3000	1	5
			3000	2	3	400	2(a)	5	400	2	5
			2000	(b)	3	4000	1	4		See clause 5.9.2.2	
			600	2(a)	3	3000	2(f)	4			
						2000	4(f)	4			
						600	2(f)	4			
D.2	Ditto	Mod	3000	1	3	2400	1	5	See clause 5.9.2.2		
			2000	2	3	300	2(a)	5			
			1500	(b)	3	3000	1	4			
			500	2(a)	3	2000	2(f)	4			
						1500	4(f)	4			
						500	2(a)	4			
D.3	Ditto	High	1500	1	2	2000	1	2	See clause 5.9.2.2		
			1000	2	2	1500	2	2			
			500	(b)	2	1000	(b)	2			
1	2	3	4	5	6	7	8	9	10	11	12

NOTE:-

(a) Timber upper floor of ½ hr. F.R.R. and lined throughout with material to provide a construction having a ½ hr F.R.R. and provided there is no place of assembly, as defined herein, on the upper floor

(b) Number of storeys not limited by this table

(c) Provided the engineer may allow a larger area if he is of the opinion that the separation distance, means of egress, and other considerations warrant.

(d) Single unit dwellings only

(e) But not less than the F.R.R. in clause 5.21.3

(f) Each floor above the ground floor shall have a 1 hr. F.R.R. except that a gallery or mezzanine floor and a floor wholly within a maisonette, may have ½ hr. F.R.R.

Canada

Relationship Between the National Fire Code and the National Building Code

NBC
- establishes a satisfactory level of fire safety for the construction of new buildings or the reconstruction of old buildings

NFC
- establishes a satisfactory level for fire prevention, fire fighting and life safety in buildings

National Building Code of Canada

Part 3 Fire Protection, Occupant Safety and Accessibility

3.1.5.4 Combustible glazing and Skylights

4) The flame spread rating of combustible glazing is permitted to be not more than 150 if the aggregate area of the glazing is not more than 25% of the wall area of the storey in which it is located and
   a) the glazing is installed in a building not more than 1 storey in building height,
   b) the glazing in the first storey is separated from the glazing in the second storey in accordance with the requirements of Article 3.2.3.16. for opening protection, or
   c) the building is sprinklered throughout

3.1.5.5 **Combustible Components for Exterior Walls**

1) Except for an exposing building face required to conform to Sentence 3.2.3.7(1) or Sentence 3.2.3.7(4), an exterior non loadbearing wall assembly that includes combustible component is permitted to be used in a building required to be of non combustible construction provided
   a) the building is
      i) not more than 3 storeys in building height or,
      ii) sprinklered throughout.

3.1.5.11 Combustible Insulation and its Protection

3) Combustible insulation having a flame spread rating more than 25 but not more than 500 on an exposed surface, or any surface that would be exposed by cutting through the material in any direction, is permitted in the exterior walls of a building required to be of non combustible construction, provided the insulation is protected from adjacent spaces within the building, other than adjacent concealed spaces within the wall assemblies, by a thermal barrier as described in Sentence (2), except that in a building that is sprinklered throughout and is more than 18 m high, measured between grade and the floor level of the top storey, the insulation shall be protected by a thermal barrier consisting of
   a) not less than 12.7 mm thick gypsum board mechanically fastened to a supporting assembly independent of the insulation
   b) lath and plaster, mechanically fastened to a supporting insulation independent of the insulation,
   c) masonry
   d) concrete, or,
   e) any thermal barrier that meets the requirements of classification B when tested in conformance with CAN4-S124-M "Standard Method of Test for the Evaluation of Protective Coverings for Foamed Plastic

3.1.5.12 **Combustible Elements in Partitions**

3) Solid lumber partitions not less than 38 mm thick and partitions containing wood framing are permitted to be used in a building required to be of non combustible construction provided
   a) the building is sprinklered throughout
   b) the partitions are not
      i) located in any care or detention occupancy
      ii) installed as enclosures for exits or vertical service spaces, or,
      iii) used to satisfy the requirements of Clause 3.2.8.1.(1)(a).

3.1.5.15 **Combustible Piping Materials**

2) Combustible sprinkler piping is permitted to be used within a sprinklered floor area in a building required to be of non combustible construction
3) Polypropylene pipes and fittings are permitted to be used for drain, waste and vent piping for the conveyance of highly corrosive materials and for piping used to distribute distilled or dialysed water in laboratory and hospital facilities in a building required to be of non combustible construction provided
   a) the building is sprinklered throughout
   b) the piping is not located in a vertical shaft, and,
   c) piping that penetrates a fire separation is sealed at the penetration by a fire stop system that when subjected to the fire test method in CAN4-S115-M, "Standard Method of Fire Tests of Firestop Systems", has an FT rating not less than the fire resistance rating of the fire Separation.

3.1.8.6 **Maximum Openings**

1) The size of an opening in an interior fire separation required to be protected with a closure shall be not more than 11 m^2, with no dimension more than 3.7 m, if a fire compartment on either side of the fire separation is not sprinklered.
2) The size of an opening in an interior fire separation required to be protected with a closure shall be not more than 22 m^2, with no dimension more than 6 m, provided the fire compartments on both sides of the fire separation are sprinklered.

3.1.9.4 **Combustible Piping Penetrations**

1) Combustible sprinkler piping is permitted to penetrate a fire separation provided the fire compartments on either side of the fire separation are sprinklered

3.1.11.5 **Fire Stopping of Roof Spaces, Balconies and Canopies**

1) A concealed space within a ceiling or roof assembly of combustible construction, including an attic or roof space, in which sprinklers are not installed, shall be separated by construction conforming to Article 3.1.11.7 into compartments not more than
   a) 600 m^2 in area with no dimension more than 60 m if the exposed construction materials within the space have a flame spread rating of not more than 25, and
   b) 300 m^2 in area with no dimension more than 20 m if the exposed construction materials within the space have a flame spread rating of more than 25

3.1.11.6 **Fire Stopping of Crawl Spaces**

1) A crawl space which is not considered as a basement by Article 3.2.2.9, and in which sprinklers are not installed, shall be separated by construction conforming to Article 3.1.11.7 into compartments not more than 600 m^2 with no dimension more than 30 m

3.1.13.2 **Flame Spread Rating**

1) Except as otherwise required or permitted by this sub section, the flame rating of the interior walls and ceiling finishes including glazing and skylights, shall be no more than 150 and shall conform to table 3.1.13.2

Table 3.1.13.2
Flame Spread Ratings
Forming Part of Sentence 3.1.13.2.(1)

Occupancy Location or Element	Maximum Flame Spread Rating for walls and Ceilings	
	Sprinklered	Not Sprinklered
Group A Division 1 occupancies, including doors, skylights, glazing and light diffusers and lenses	150	75
Group B Occupancies	150	75
Exits	25	25
Lobbies described in sentence 3.4.4.2.(2)	25	25
Covered vehicular passageways, except for roof assemblies of heavy timber construction in the passageways	25	25
Vertical service Spaces	25	25

3.1.13.7 **High Buildings**

1) Except as permitted in Sentences (2) to (4), the interior wall, ceiling and floor finishes in a building regulated by the provision of Subsection 3.2.6 shall conform to the flame spread rating requirements in Article 3.1.13.2 and to the flame spread rating and smoke developed classification values in Table 3.1.13.7
2) Except for a building of group B major occupancy and elevator cars, the flame spread rating and smoke developed classification of interior wall, floor and ceiling finishes need not conform to the values in Table 3..1.13.7, providing the building is sprinklered throughout.

3.2.1.2. **Storage Garage Considered as a Separate Building**

2) The exterior wall of a basement that is required to be a fire separation with a fire resistance rating in accordance with Sentence (1) is permitted to be penetrated by openings that are not protected by closures providing
   a) The storage garage is sprinklered throughout

3.2.2.16 **Heavy Timber Roof Permitted**

1) Unless otherwise permitted by Articles 3.2.2.20 to 3.2.2.83, a roof assembly in a building up to 2 storeys in building height is permitted to be of heavy timber construction regardless of the building area or type of construction required, providing the building is sprinklered throughout.

3.2.3.15 **Protection of Soffits**

1) Except as permitted in Sentences (3) or (4), where there is a common attic or roof space above more than 2 suites of a residential occupancy or above more than 2 patients' sleeping rooms, and the common attic or roof space projects beyond the exterior wall of the building, the soffit, and any opening in the soffit or other surface of the projection located within 2 500 mm of a window or door opening shall be protected by
   a) non combustible material
   b) plywood not less than 11 mm thick
   c) lumber not less than 11 mm thick
4) The protection required by Sentence (1) for projections is permitted to be omitted if
   a) the fire compartments behind the window and door openings are sprinklered in accordance with Article 3.2.5.13, and,
   b) all rooms, including closets and bathrooms, having openings in the wall beneath the soffit are sprinklered

3.2.5.9 **Standpipe System Design**

5) The residual design pressure at the deign flow rate of the topmost hose connection of a standpipe system that is required to be installed in a building is permitted to be less than 690 kPa provided,
   a) the building is sprinklered throughout

3.3.1.4. **Public Corridor Separations**

1) Except as otherwise required by this part or permitted by Sentences (2) to (7), a public corridor shall be separated from the remainder of the building by a fire separation having a fire resistance of not less than 1 hr.
2) If a floor area is sprinklered throughout, no fire separation is required between a public corridor and the remainder of the floor area provided the public corridor
   (a) is more than 5 m unobstructed width, and
   (b) does not serve
      i) a care or detention occupancy
      ii) a residential occupancy

3.3.1.1 **Separation of Suites**

3) Occupancies that are served by public corridors conforming to Section 3.3.1.4.(5) in a building that is sprinklered throughout, are not required to be separated by fire separations provided the occupancies are
   a) suites of business and personal services occupancies
   b) fast food, vending operations that do not provide seating for customers, and
   c) suites of mercantile occupancy

3.3.1.4 **Public Corridor Separations**

3) If a floor area is sprinklered throughout, no fire resistance rating is required for a fire separation between a public corridor and the remainder of the floor area provided the corridor does not serve a care or detention occupancy or a residential occupancy
4) If a floor area is sprinklered throughout, no fire separation is required between a public corridor and the remainder of the floor area provided the public corridor
   a) is more than 5 m in unobstructed width, and
   b) does not serve
      i) a care or detention occupancy, or
      ii) a residential occupancy
5) If a floor area is sprinklered throughout, no fire separation is required between a room or a suite and a public corridor that serves it provided the public corridor complies with Sentence 3.3.1.9.(6) (width and area) and Clause 3.4.2.5.(1)(d) (width and length)
6) If a floor area is sprinklered throughout, no fire separation is required between a public corridor and a room containing water closets and lavatories provided the room and the public corridor are separated from the remainder of the floor area by a fire separation that has a fire resistance rating not less than that required between the public corridor and the remainder of the floor area.

3.3.1.5 **Egress Doorways**

1) Except for dwelling units, a minimum of two egress doorways located so that one doorway could provide egress from the room or suite as required by Article 3.3.1.3. if the other doorway becomes inaccessible to the occupants due to a fire which originates in the room or suite, shall be provided for every room and every suite
    - c) in a floor area that is not sprinklered throughout, and
        - i) the area of the room or suite is more than the value in Table 3.3.1.5.A., or
        - ii) the travel distance within the room or suite, to the nearest egress doorway, is more than the value in Table 3.3.1.5.A.,or
    - d) in a floor area that is sprinklered throughout and does not contain a high hazard industrial occupancy and
        - i) the travel distance to the egress doorway is more than 25 m, or
        - ii) the area of the room or suite is more than the value in Table 3.3.1.5.B

TABLE 3.3.1.5.A
Egress in Floor area not Sprinklered Throughout

Occupancy of Room or Suite	Maximum area of Room or Suite	Maximum Distance to Egress Doorway
Group A	150	15
Group C	100	15
Group D	200	25
Group E	150	15
Group F Division 2	150	10
Group F Division 3	200	15

TABLE 3.3.1.5.B.
Egress in Floor Area Sprinklered Throughout

Occupancy of Room or Suite	Maximum Area of Room or Suite
Group A	200
Group B Division 1	100
Group B Division 2	
Sleeping Area	100
Group B Division 2	
Other the sleeping	200
Group C	150
Group D	300
Group E	200
Group F Division 2	200
Group F Division 3	300

3.3.1.20. **Janitors' Rooms**

3) The fire separation required by Sentence (1) is not required to have a fire resistance rating if the floor area in which the room or space is sprinklered throughout

3.3.1.21. **Common Laundry Rooms**

3) The fire separation required by Sentence (1) is not required to have a fire resistance rating if the floor area in which the laundry room is located is sprinklered throughout.

3.3.2.5. **Corridors**

3) The fire resistance rating required by Sentence (1) is permitted to be waived if the floor area in which the corridor is located is sprinklered throughout

3.3.2.11. **Libraries**

2) The fire separation required by Sentence (1) is not required if the book storage room is sprinklered

3.3.2.12. **Stages for Theatrical Performances**

6) The fire separation referred to in Sentence (3) is not required between a stage and a seating area in a building that is sprinklered throughout, providing that a sprinkler deluge system is installed at the boundary between the stage and the seating area

3.3.4.2. **Fire Separations**

4) The fire resistance rating of the fire separation required by Sentence 3.3.5.6.(1) is permitted to be waived if the fire separation is located between a dwelling unit and an attached storage garage containing no more than 5 vehicles, provided
   a) the dwelling unit and the attached storage garage are sprinklered

3.3.5.9. **Multiple Tenant Self Storage Warehouse**

1) Unless te building is sprinklered throughout, each individual tenancy in a multiple tenant self storage warehouse classified as an industrial occupancy shall be separated from the remainder of the building by a fire separation have a fire resistance rating not less than 45 min.

3.4.2.4. **Travel Distance**

2) The travel distance from a suite or room not within a suite is permitted to be measured from an egress door of the suite or room to the nearest exit provided
   a) the suite or room is separated from the remainder of the floor by a fire separation
      i) having a fire resistance rating not less than 45 min. in a floor area that is not sprinklered throughout, or
      ii) which is not required to have a fire resistance rating in a floor area that is sprinklered throughout.

3.4.2.5. **Location of Exits**

1) Except as permitted by sentences (2), (3) and 3.3.2.4.(6), if more than one exit is required from a floor area, the exits shall be located so that the travel distance to at least one exit shall not be more than
   a) 25 m in a high hazard occupancy
   b) 40 m in a business and personal services occupancy
   c) 45 m in a floor area that contains an occupancy other than a high hazard industrial occupancy, provided it is sprinklered throughout,
   d) 105 m in any floor area served by a public corridor, in which rooms and suites are not separated from the remainder of the floor area by a fire separation, provided
      iii) the building is sprinklered throughout

3.4.4.2. **Exits through Lobbies**

2) Not more than one exit from a floor area is permitted to lead through a lobby provided
   e) the lobby conforms to the requirements for exits, except that
      iii) the fire separation between the lobby and adjacent occupancies that are permitted to open onto the lobby need not have a fire resistance rating provided the lobby and the adjacent occupancies are sprinklered

3.4.6.16. **Security for Banks and Mercantile Floor Areas**

1) If a building is sprinklered throughout, the requirements of Sentence 3.4.6.15.(1) (Internal Release) are permitted to be waived for exit and egress doors complying with Sentence (2) to (9) that serve a floor area or part of a floor area used exclusively for
   a) a bank, or
   b) the sale of retail merchandise

3.6.2.2. Waiver of Fire Separations

2) The fire separation required by Sentence 3.6.2.1.(5) need not be provided if the service room is located in a floor area that is sprinklered throughout.

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3.6.2.4 Baled Combustible Fibres

1) Except as permitted in Sentences (2), (3) and (4), bales combustible fibres shall be stored so that
   a) no individual storage area exceeds 250 m^2
   b) the height of any storage in an individual storage area does not exceed 4.5 m
   c) subsidiary aisles within individual storage areas are not less than 1 m wide and,
   d) the clearance between piles and building walls is not less than 1 m

1) Except as permitted in Sentence (4), where bales combustible fibres are stored in sprinklered buildings, the maximum area of any individual storage area shall be 500 m^2

2) Where baled raw pulp is stored in an unsprinklered building
   a) the maximum area of any individual storage area shall be 500 m^2, and
   b) the maximum height of storage shall be 6 m

1) where baled raw pulp is stored in a sprinklered building
   a) the maximum area of any individual storage area shall be 1000 m^2, and
   b) the maximum height of storage shall be 6 m

3.2.7.9. Fire Suppression Systems

1) Except as permitted in Sentences (2) and (3) and in Part 4, buildings used for the storage of dangerous goods regulated by this subsection shall be equipped throughout with a sprinkler or other fire suppression system, designed in conformance with Part 6 and good engineering practice with respect to specific dangerous goods.

2) Buildings described in Sentence (1) need not be equipped throughout with a sprinkler or other fire suppression system provided that
   a) the sum of the individual storage areas in the building used for the storage of dangerous goods, other than Class 9 dangerous goods with no other classification and those covered in Part 4 of this code, does not exceed 100 m^2, and
   b) the dangerous goods are
      i) separated in conformance with Table 3.2.7.6., and
      ii) stored in fire compartments separated from the remainder of the building by a fire separation having a fire resistance rating of not less than 2 hr.

3.2.8.2 Flammable Gasses

2) Cylinders of Class 2.1 flammable, lighter than air gasses are permitted to be stored outside of a room described in Sentence (1) provided that,
   a) in an unsprinklered building of combustible construction, the aggregate capacity of expanded gas outside of the room is not more than 60 m3, and
   b) in a sprinklered building, or in a building of non-combustible construction, the aggregate capacity of expanded gas outside of the room is not more than 170 m3

4.2.5.1. Maximum Quantities

1) Except as provided in Sentence (5), the quantities of flammable liquids and combustible liquids stored in mercantile occupancies shall not exceed those in Sentences (2) to (4)

2) In unsprinklered mercantile occupancies, the maximum quantity of flammable liquids and combustible liquids permitted to be stored in a single suite shall be the lesser of
   a) 8 L/m^3 of the total area in the suit, provided that more than 2 L/m^3 is Class I Liquid, of which not more than 0.3 L/m^3 shall be Class IA, Class IB, or any combination of these 2 classes, or
   b) 8 000 L, provided that not more than 2 000 L is Class I Liquid, of which not more than 300 L shall be Class IA, Class IB, or any combination of these 2 classes.

1) In sprinklered mercantile occupancies, the maximum quantities of flammable liquids and combustible liquids permitted to be stored in a single suite shall be the lesser of
   a) 24 L/m^3 of the total area in the suit, provided that more than 6 L/m^3 is Class I Liquid, of which not more than 0.3 L/m^3 shall be Class IA, Class IB, or any combination of these 2 classes, or
   b) 24 000 L, provided that not more than 6 000 L is Class I Liquid, of which not more than 1 000 L shall be Class IA, Class IB, or any combination of these 2 classes

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